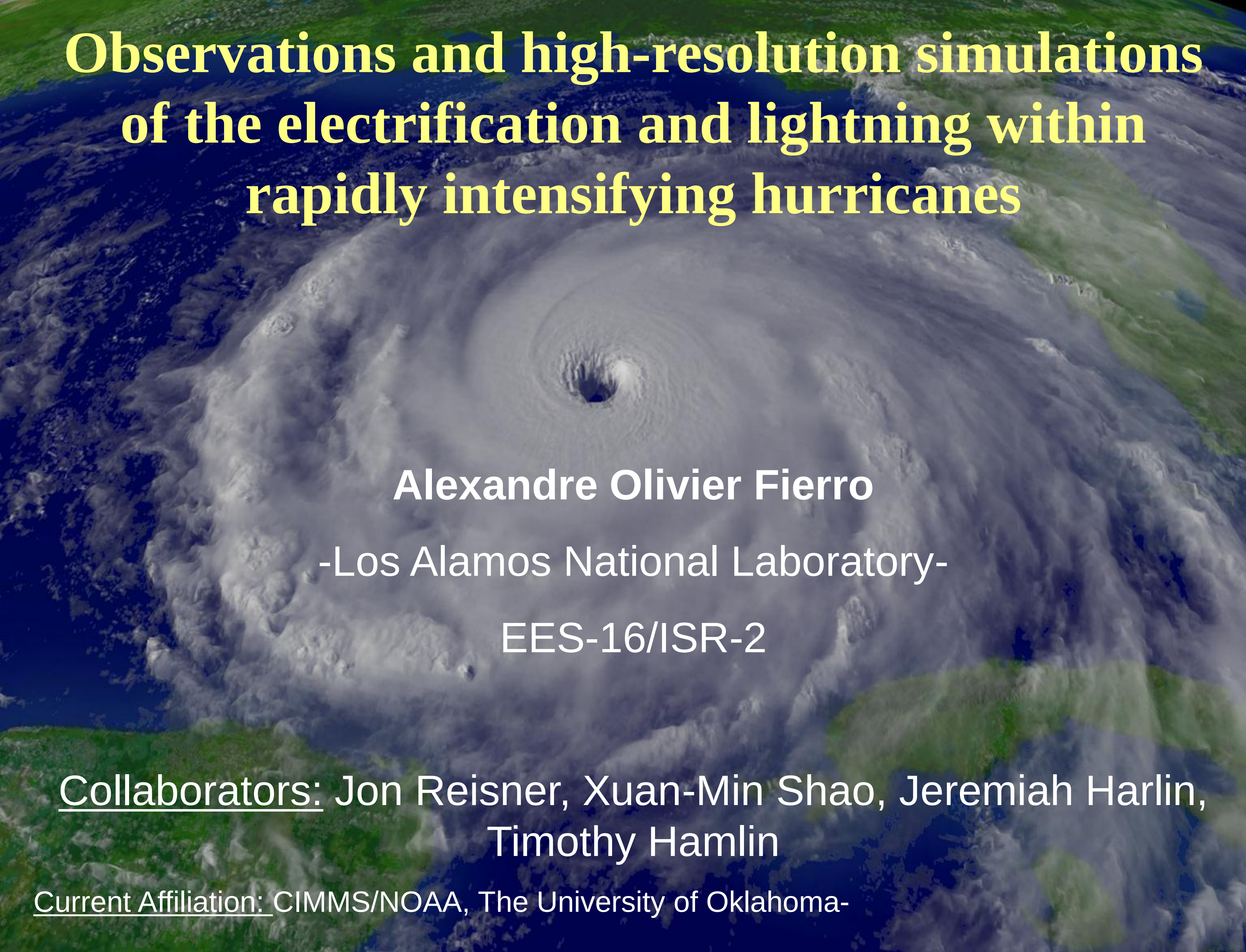

Observations and high-resolution simulations of the electrification and lightning within rapidly intensifying hurricanes

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EES-16/ISR-2

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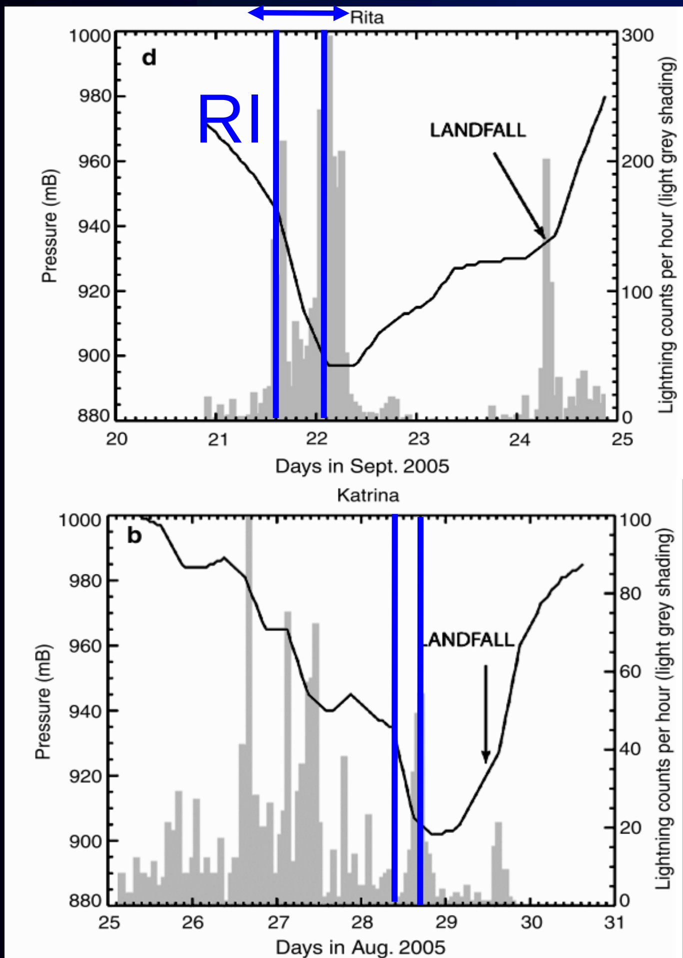
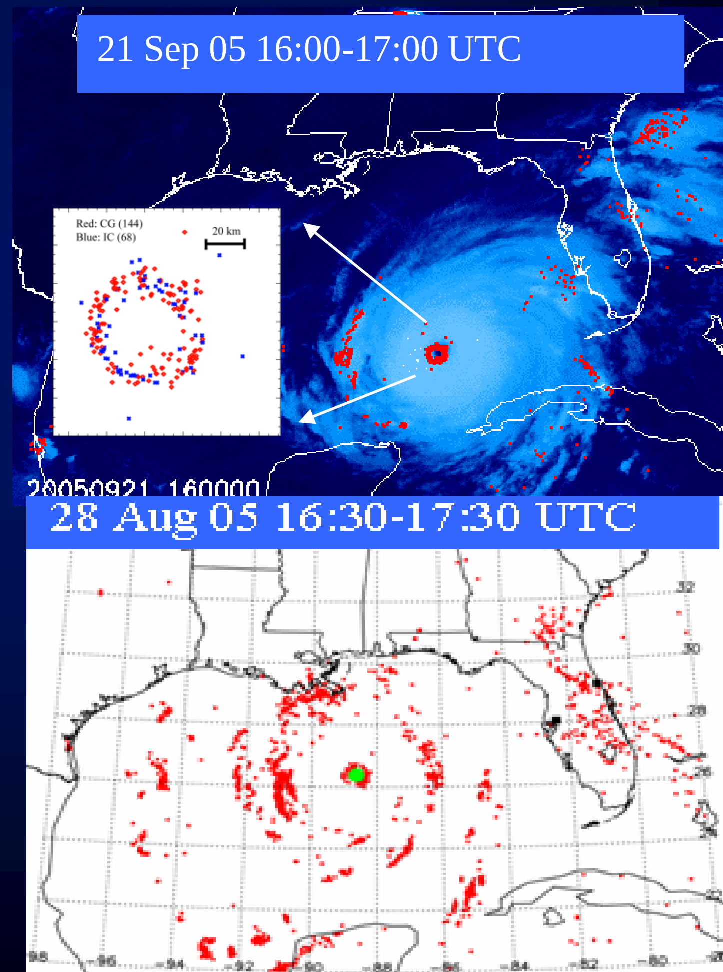
Why investigating lightning in hurricanes ?

- Observations suggests that hurricane eyewall total lightning flash rate is often accompanied by rapid intensification (RI) of the system (e.g., Molinari's, Price et al.).



Rita

Katrina



Shao et al. (2006)

Scientific goals ctd..:

•Therefore a natural question to ask is:

Can lightning data be used as a forecast tool within NWP models to better predict RI in real time?

•10’s of thausands of LASA lightning waveforms for 3 major hurricanes were manually analyzed to provide a best estimate of the observed total eyewall lightning evolution for those storms during RI.

•The following lightning attributes were determined:

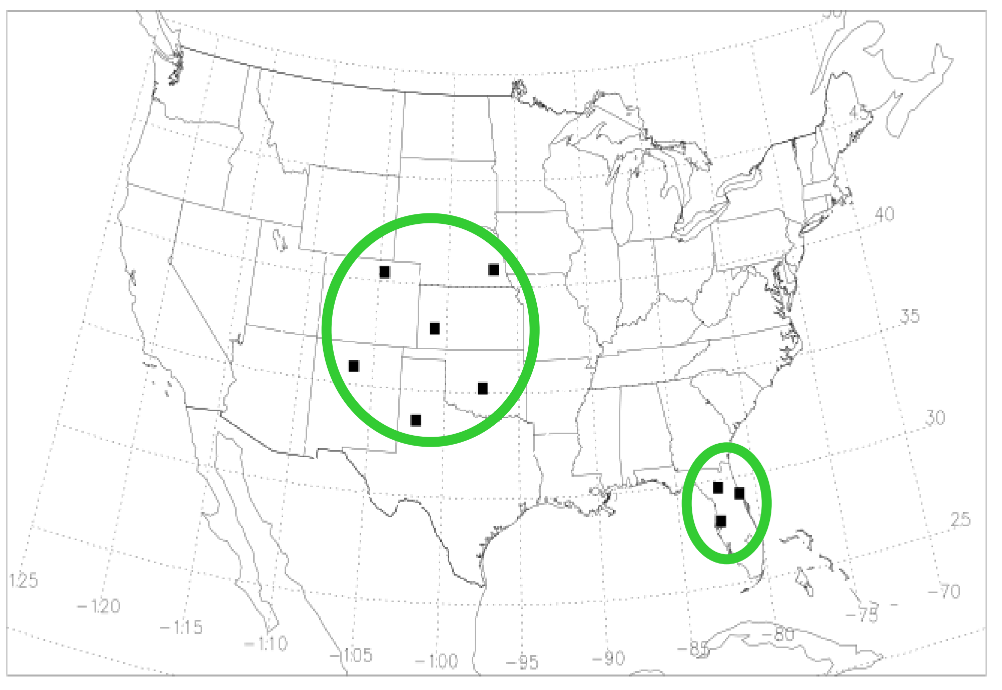
-Spatial distribution (geolocation)

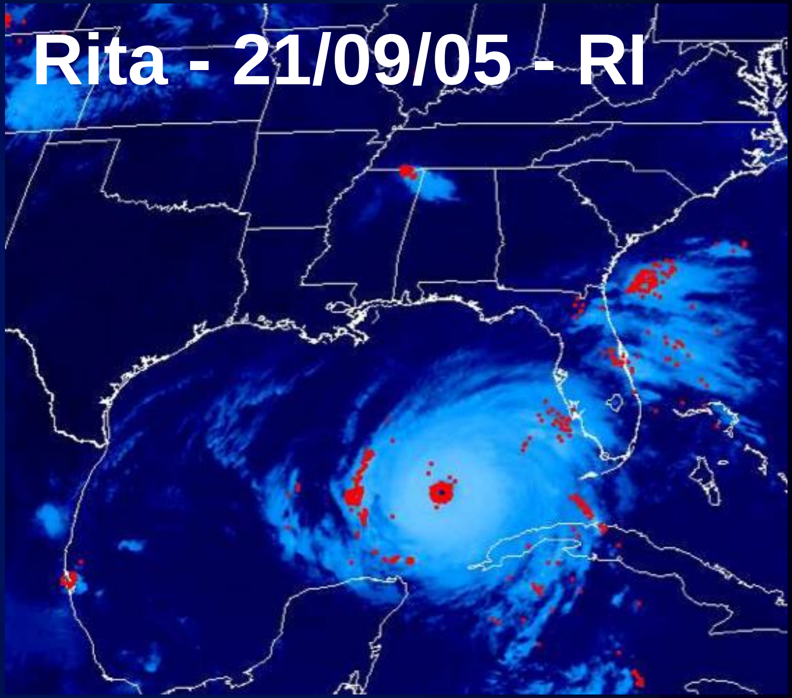
-Polarity and type

-Discharge heights

LASA network in a nutshell

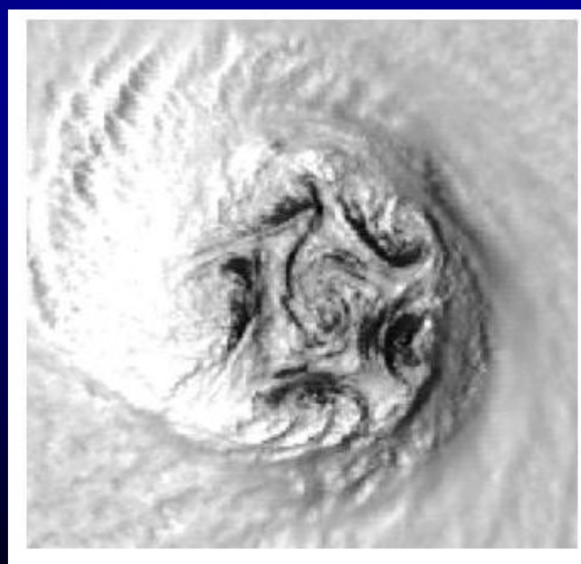
•The LASA station arrays consists of 2 groups of (VLF) stations located in the Great Plains and in Northern Florida:



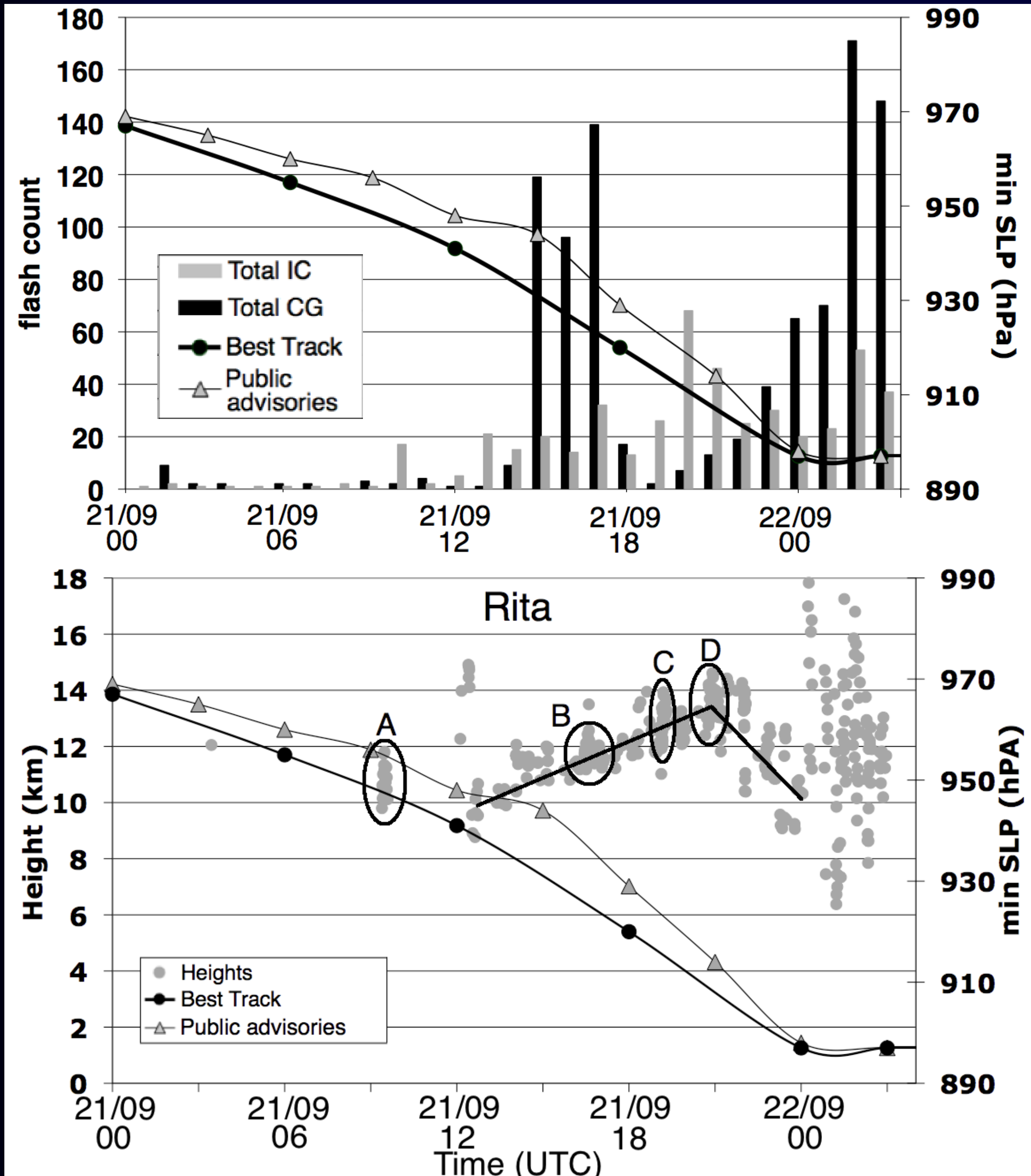


•Which for storms undergoing RI in the Central Gulf is ideal in terms of more accurate lightning geo-location (Time of Arrival algorithm).

Observations: Results

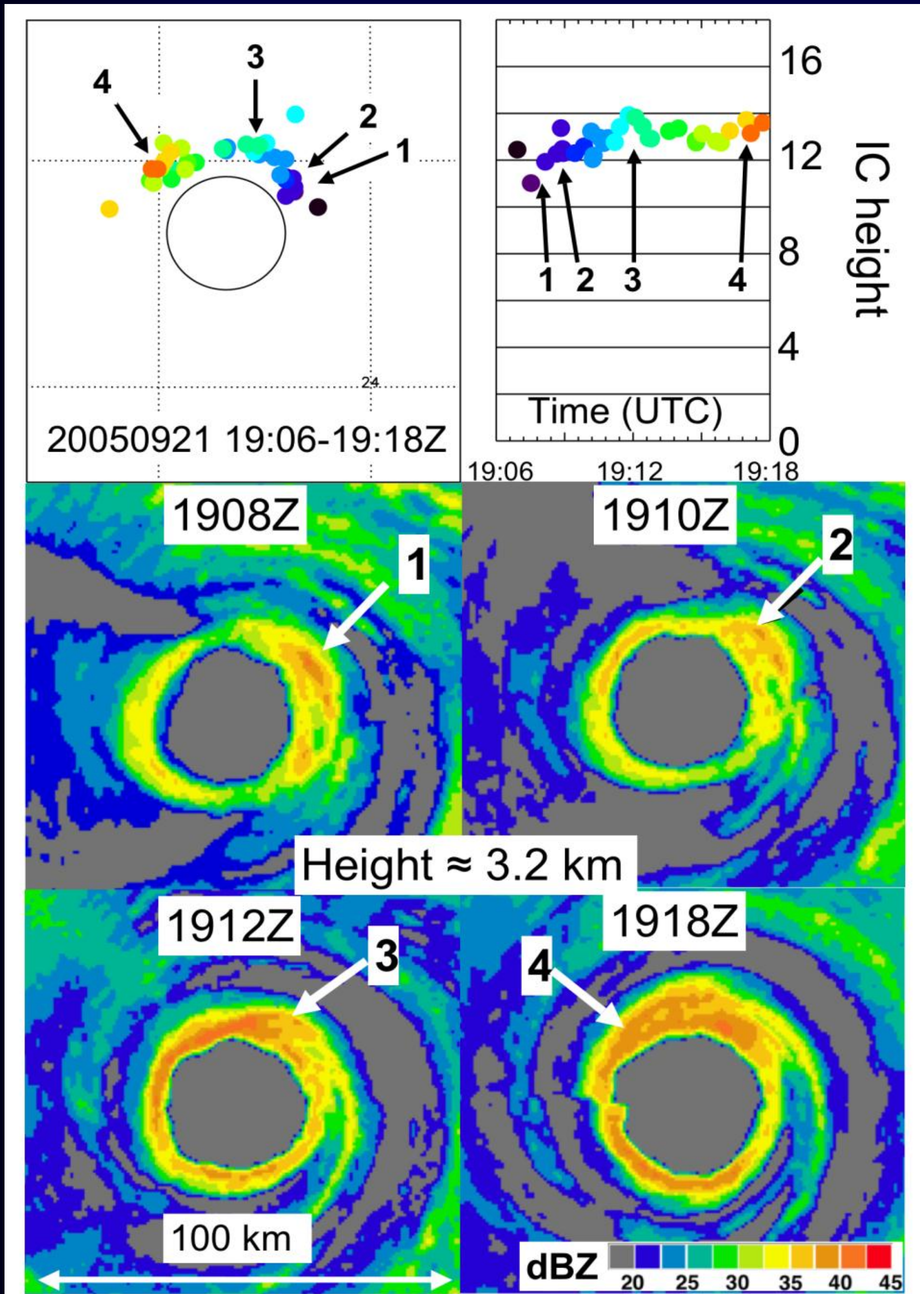


Lightning/discharge height time series for Rita



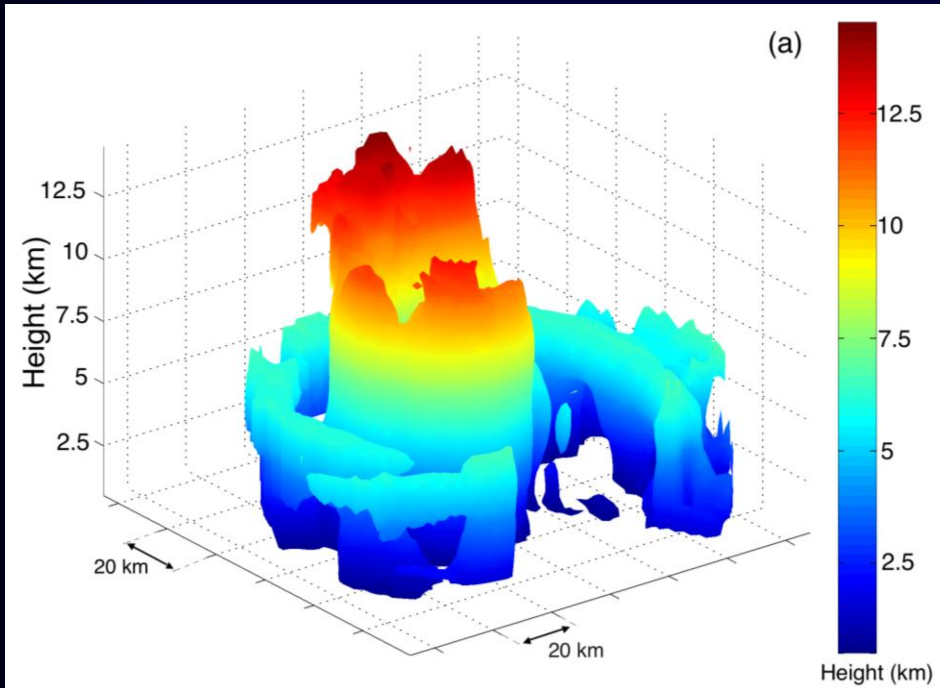
- Increase in both cloud-to-ground (CG) and intra-cloud (IC) flash rate during onset of RI
- Increase in discharge height during RI by ~ 4 km.
- Indicative of charge lofting during convective burst.
- Heights decrease quickly ~3 h before period of max intensity → Indicative of collapse of hot towers.
- Similar behavior seen for Katrina and Charley

RITA: Relationship between convective bursts & lightning



- Burst labeled C
- For a period of 12 min - IC flashes are found to rotate around the eye
- IC flashes collocated with highest radar reflectivity at z=3 km
- → IC flashes can be use to map individual hot towers during RI → IC give crucial information on core internal convective structure/state during RI

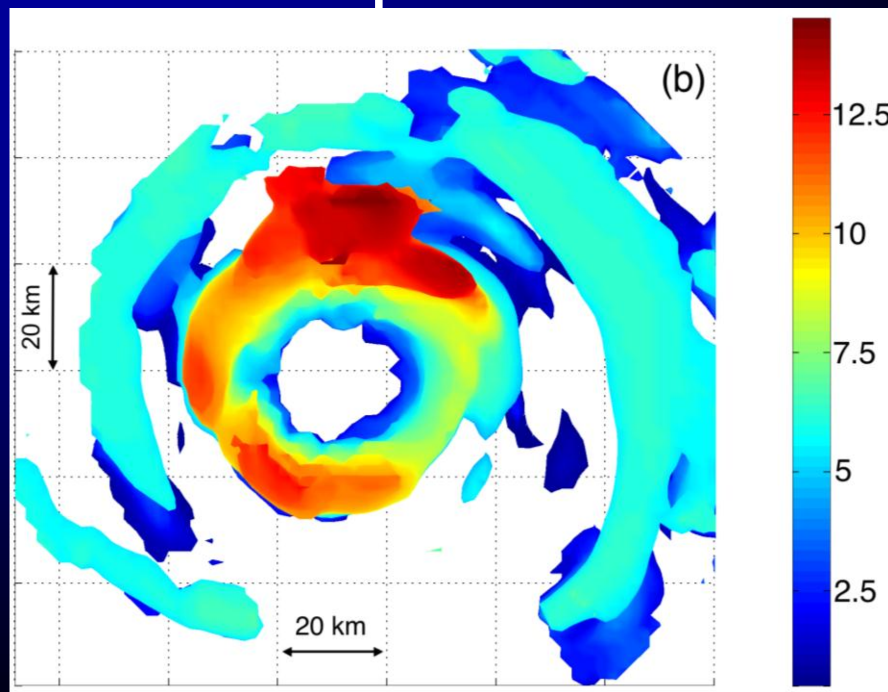
RITA: 3D view reflectivity at 1915 Z (burst C)



Side View

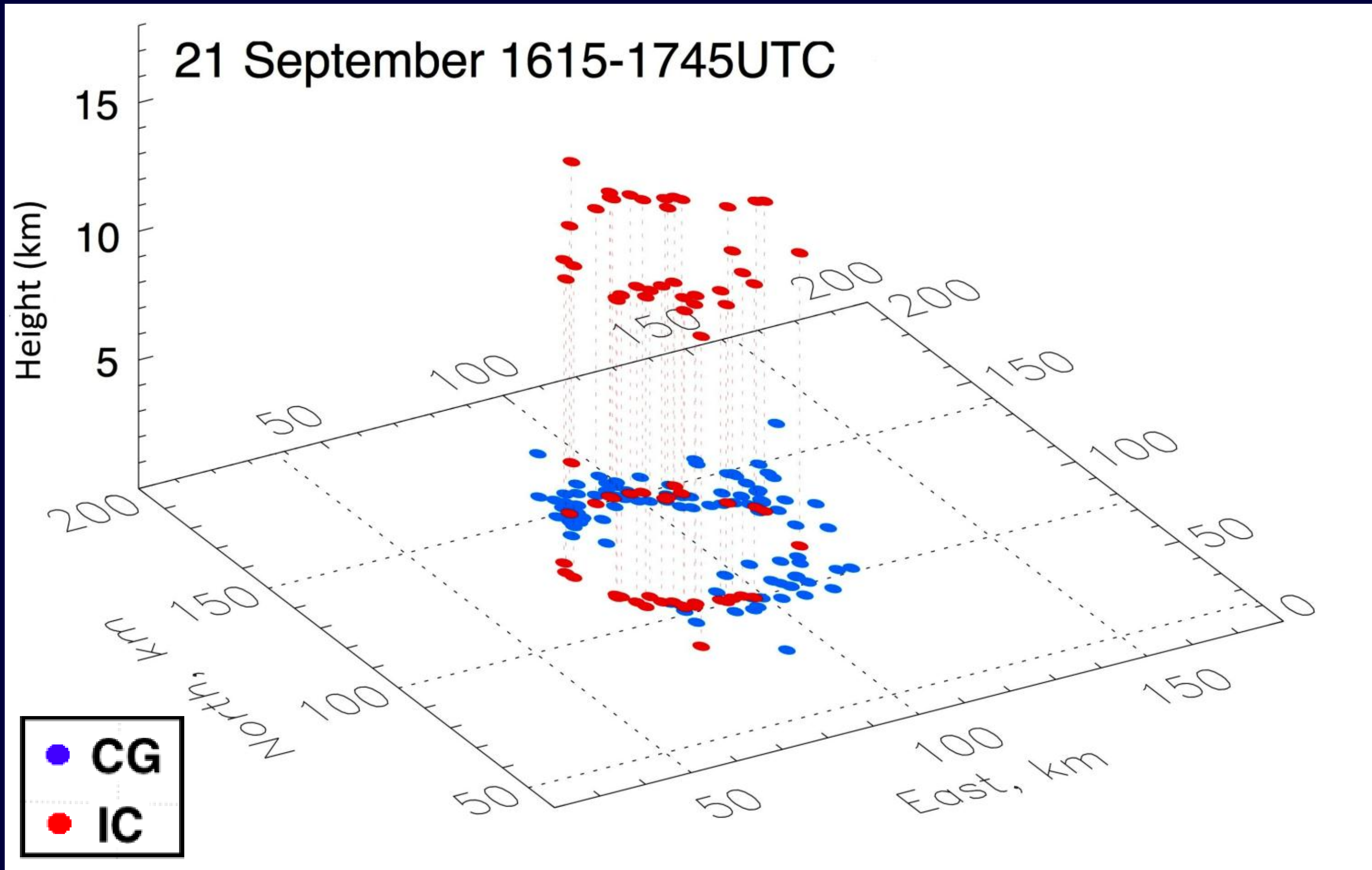
•30 dBZ echo isosurface of lower fuselage aircraft in situ data

Top view



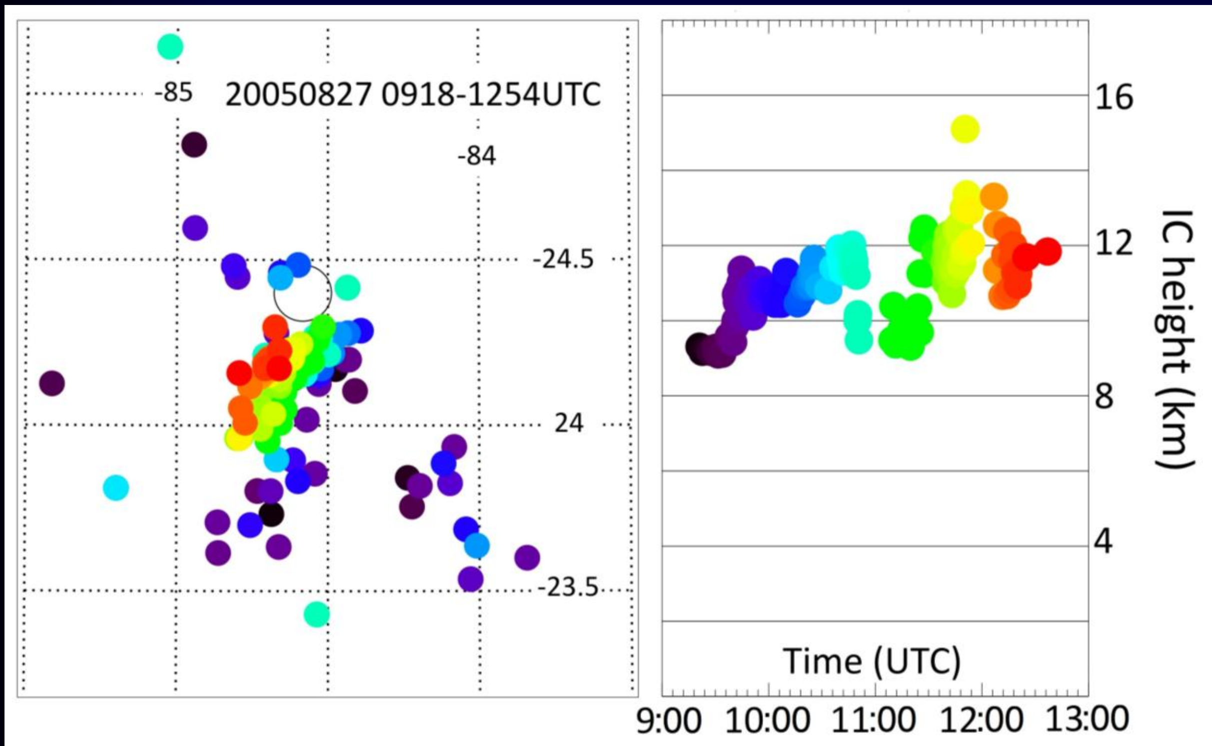
•Northern portion of the eyewall as suggested by IC flash has deeper reflectivity cores and thus updrafts

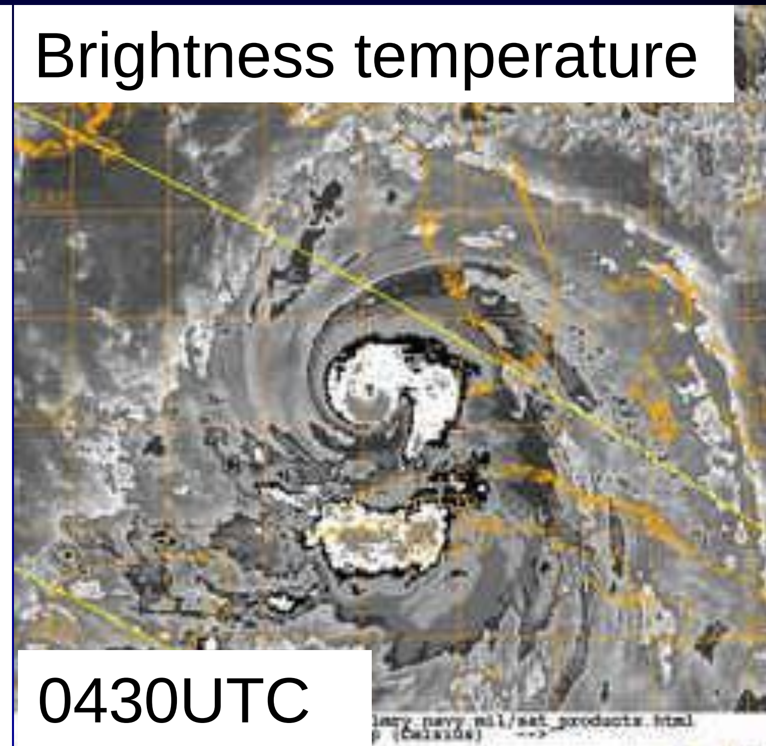
Rita: Snapshot 3D view near that time..



Little-no vertical tilt of CG and IC → Little lateral displacement of charge layers in eyewall convection.

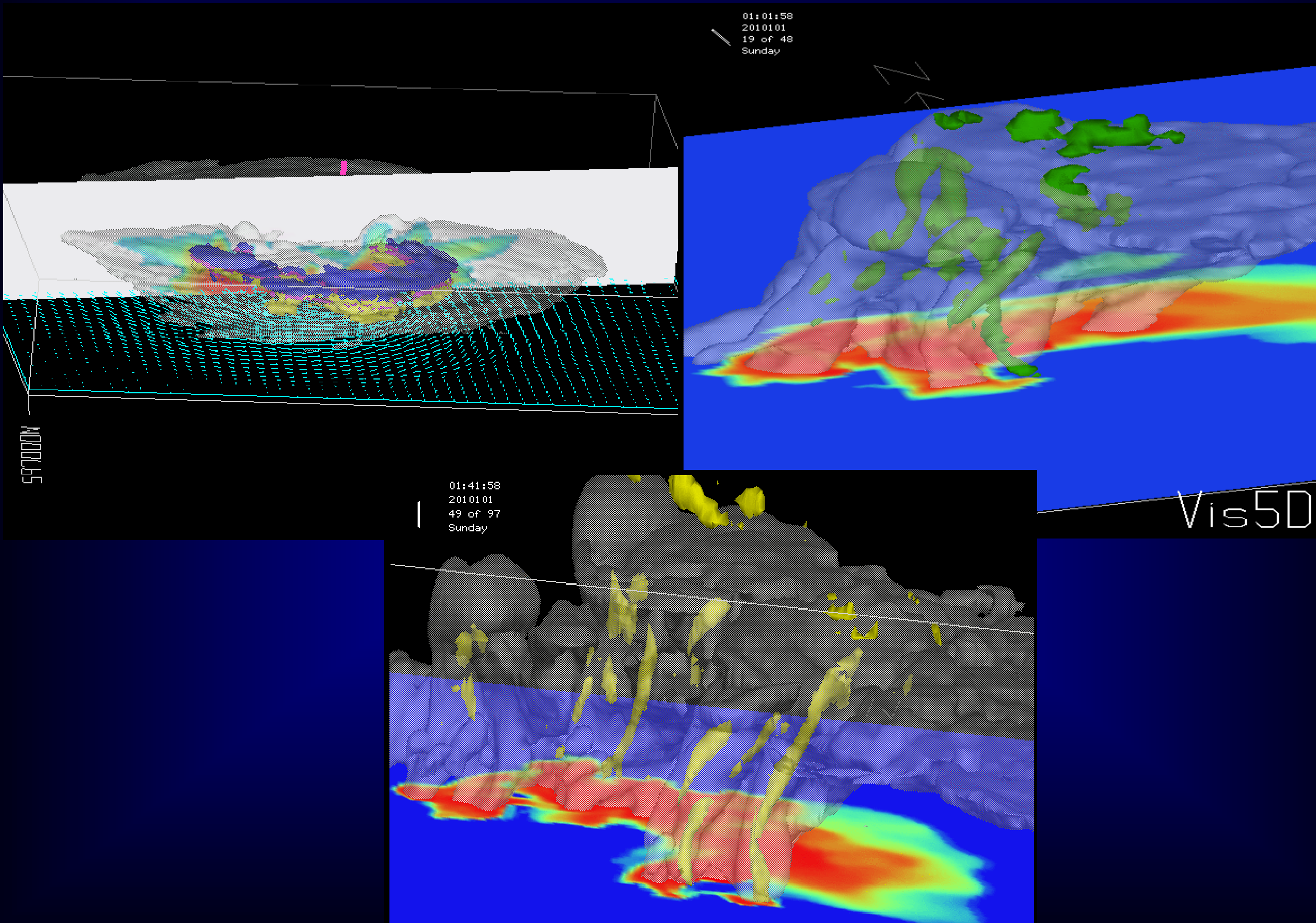
Katrina: second sets of IC bursts:





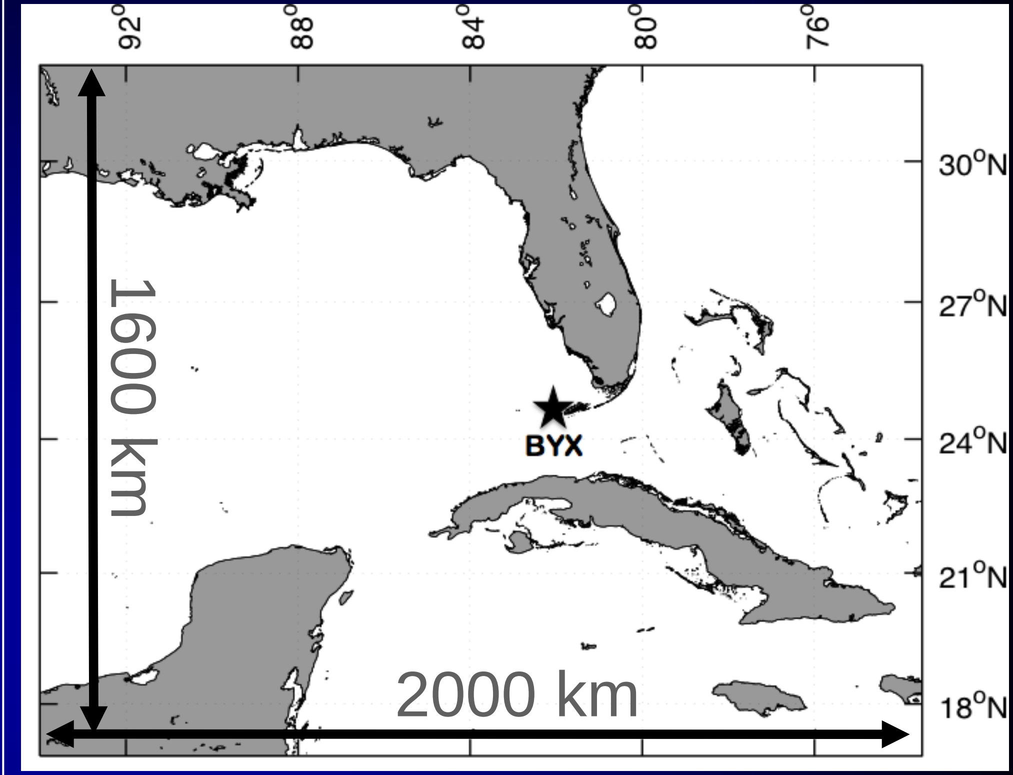
- Convection remains on the south side of the storm and follows storm track. Heights shows net 3 km rise.
- IC lightning also helps in diagnosing difference in convective regimes.

High-resolution simulations



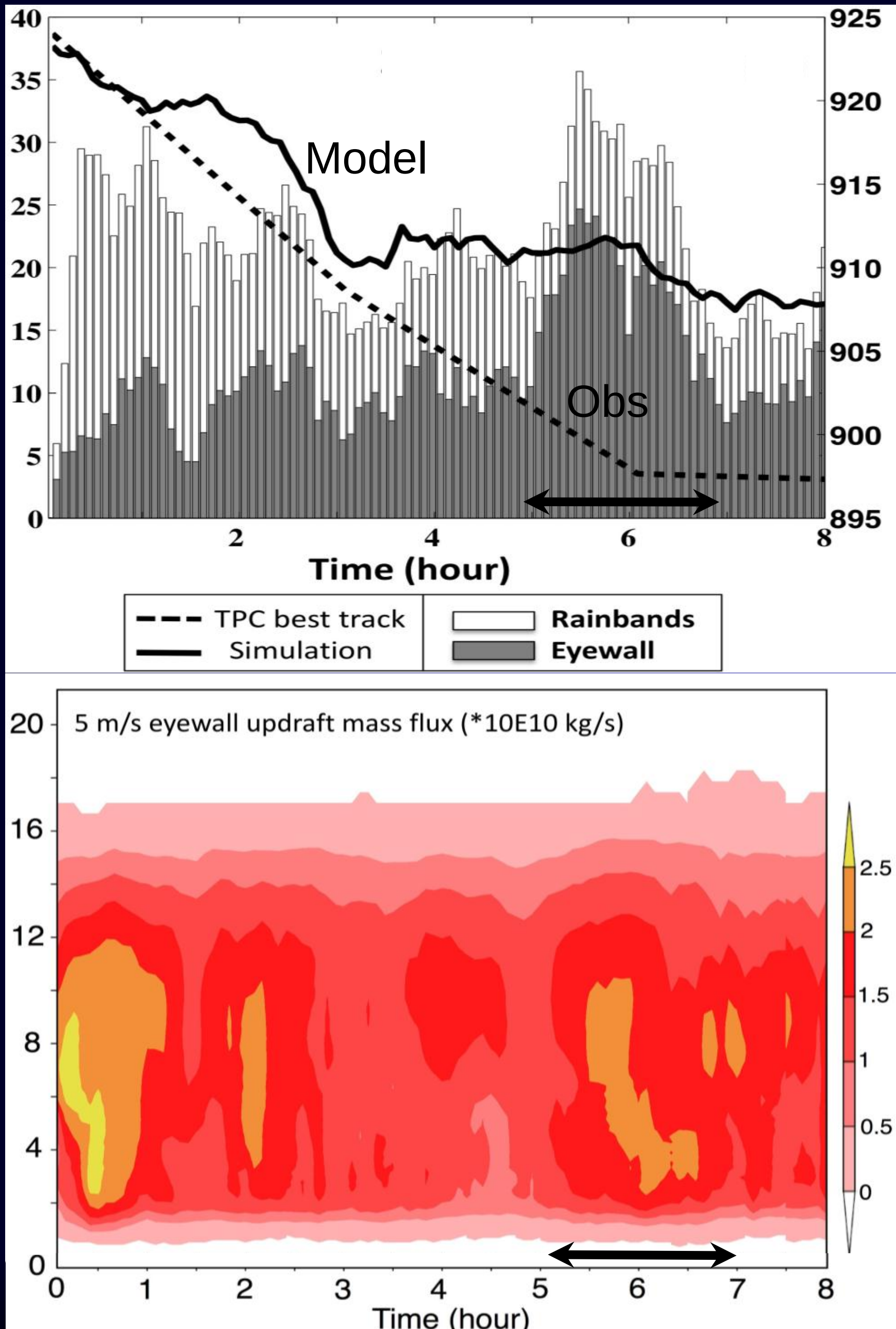
Model set-up in a flash…

- 5 bulk microphysical/hydrometeor species coupled with charging/discharge model
- No distinction between CG/IC.
- Base state thermodynamic / kinematic environment provided by ECMWF sounding.
- Vertical grid stretching from dz=50 m at the bottom to dz=700 m above 15 km.



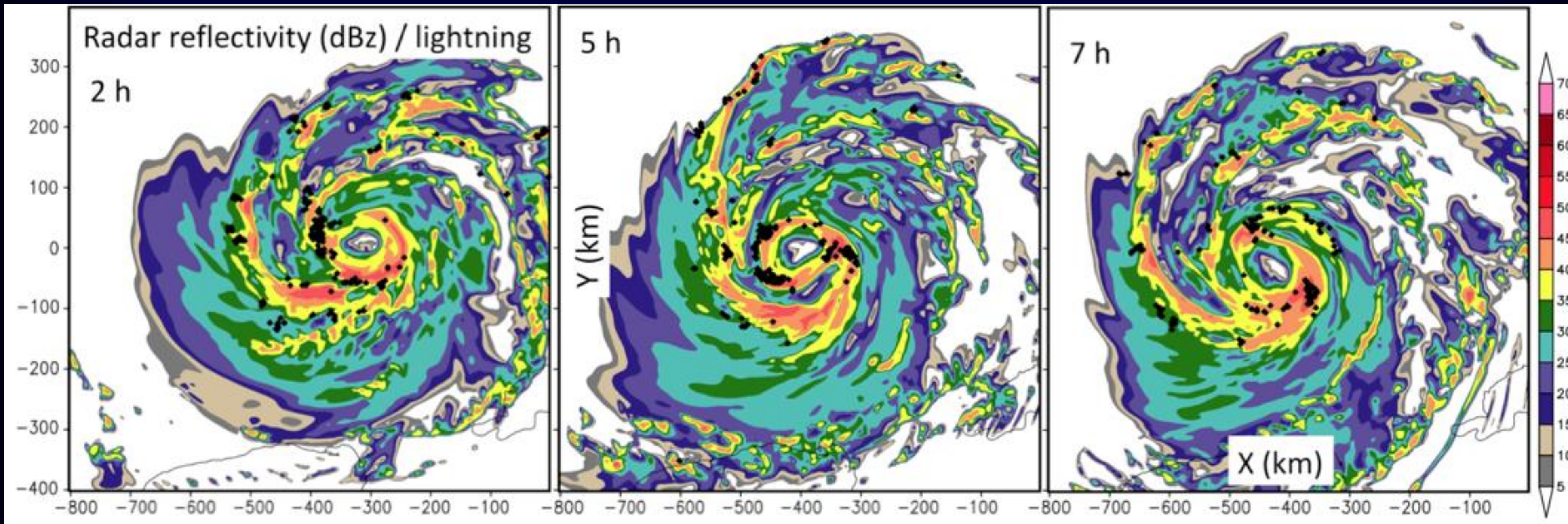
- Vortex Initialized by nudging in a bogus vortex on a 4 km grid.
- Convection in the vortex in 4 km run was hastened during first 12 h using 2D composite Doppler radar data (storm core) from Key West (BYX) and 2D lightning from LASA (outer rainbands).
- 4 km simulation ran for 38h. Then 2 km run restarted at 30h
- 2 km ran for 8h with dt=0.25s on 32000 processors (ORNL)

Lightning / Storm Intensity – Model vs Obs.



•Observations suggest that IC/CG bursts precede Rita's intensification.
•Model produced eyewall lightning burst at 5-6h followed by a ~5 hPa pressure drop.
•This lightning burst is associated with a notable uptake in eyewall updraft mass flux or convective burst as suggested by obs.

Radar reflectivity (z = 1km) / lightning discharges:



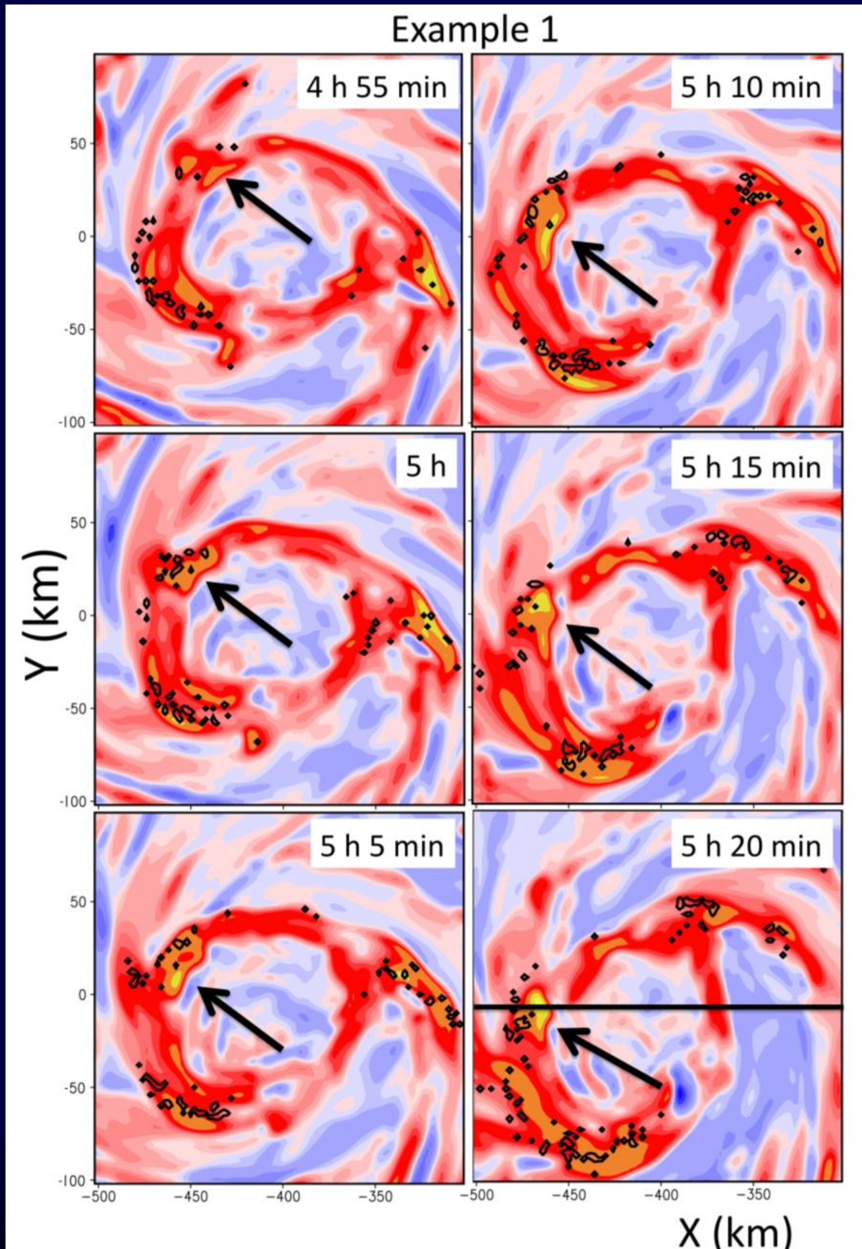
•Model does reasonable job in reproducing Rita's track, intensity evolution and structure and especially in maintaining a relatively small eye size (~30 km vs 15 km for obs)

•Episodic lightning bursts evident in the eyewall often associated with localized dBZ maxima.

•Burst at 5h associated with 3 distinct hot towers-

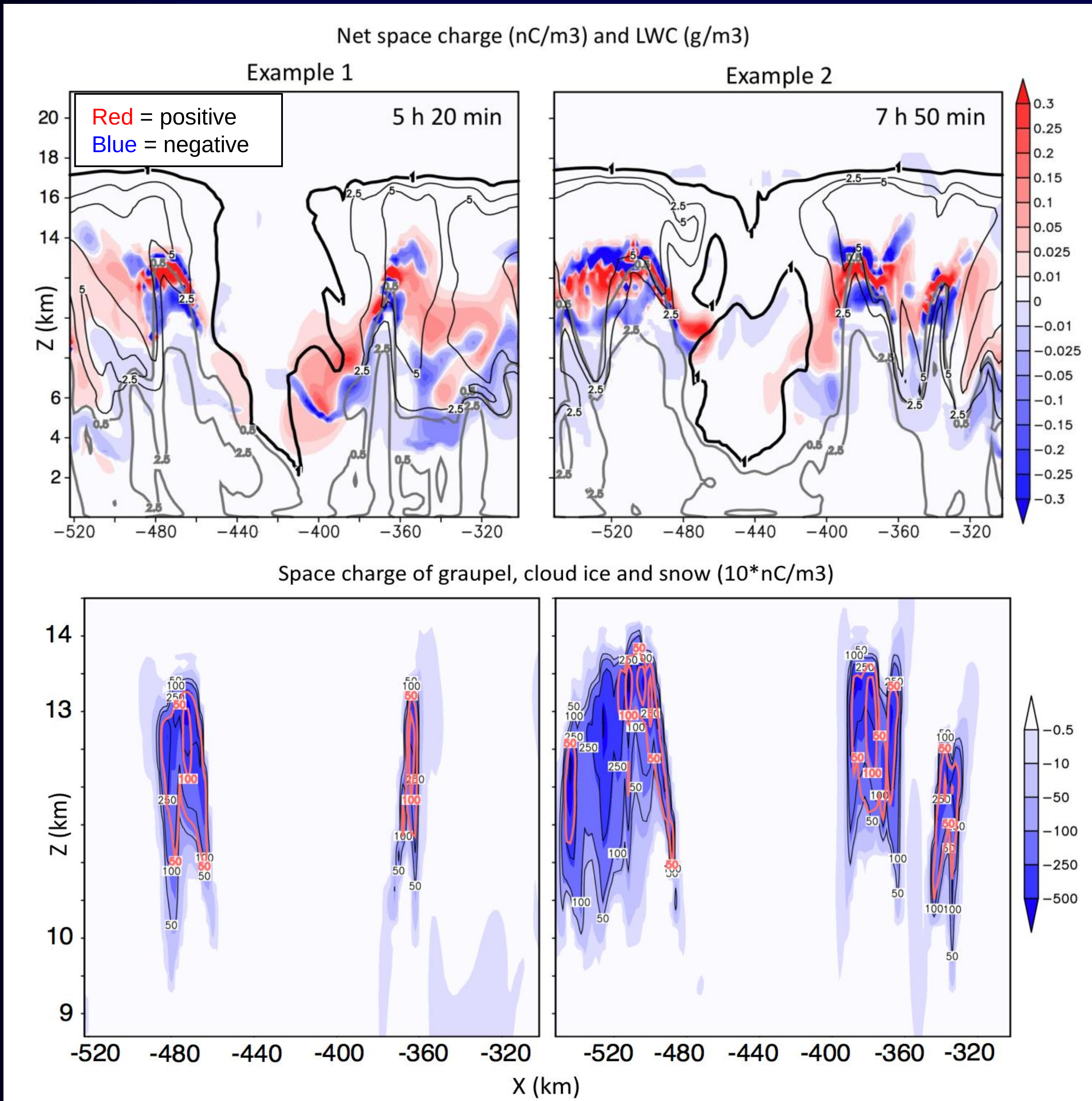
•Comparably little lightning in the rainbands consistent with obs.

Closer view of the eyewall bursts at 5 h: 7-9 km layer-averaged vertical velocities/lightning



- Made of electrically active convective elements rotating around the eyewall
- Example 1 occurs during the onset of W flux increase.
- Rotation speed less than tangential flow of primary circulation, similar to LASA observations.
- IC heights showed no increase with time in contrast to obs.

Closer view of the eyewall convection: Vertical X-Z cross sections.



- Simulated charge structure resembles an inverted tripole-while obs had normal tripole.
- Most charging occurs within the inner eyewall convection between 10-14 km atop updraft cores where graupel and LWC are found together.
- Neg charge by non-inductive charging of graupel
- Pos charge carried by ice crystals/snow

Simulated space charge of:
graupel (10*nC m-3, blue shading),
cloud ice (10*nC m-3 black contours)
snow (10*nC m-3 red contours)


Questions?

Manual analysis summary

•Ten’s of thousands of lightning waveforms recorded by LASA were analyzed for Hurricane Rita, Katrina (2005) and Charley (2004) focusing on periods of RI.

•The lightning data only focused on the storm inner core or eyewall. Why? Because key in storm intensification lies in small-scale internal core dynamics.

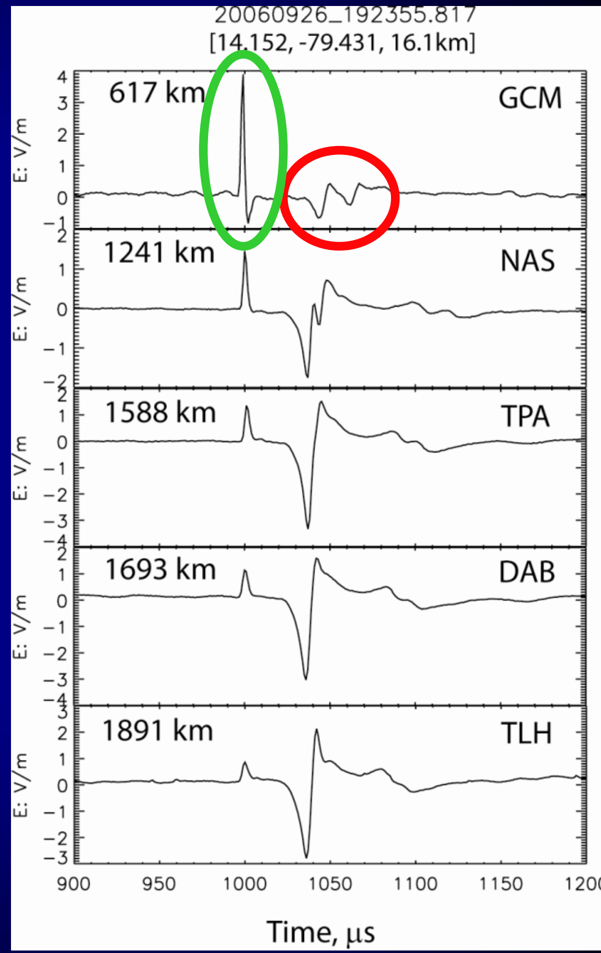
•Heights could only be determined for a particular class of intense (~20 kA) in-cloud lightning discharge called Narrow Bipolar Events (NBE).

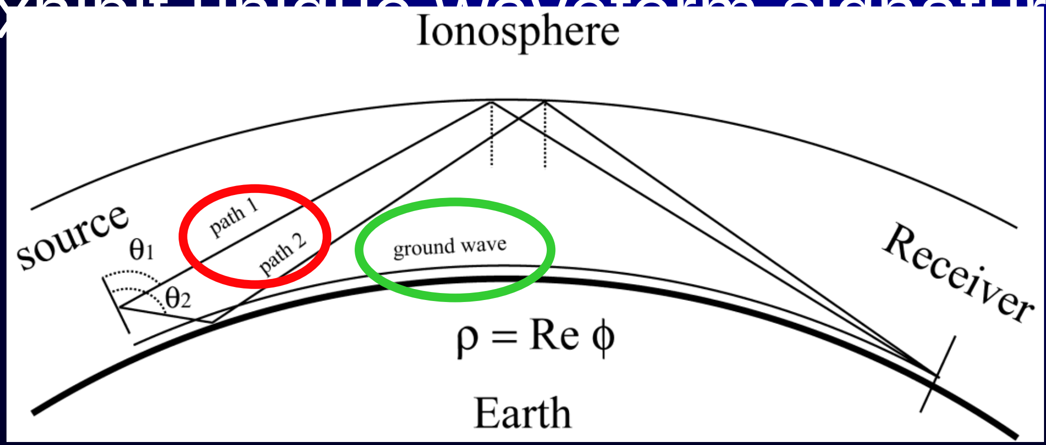
What is a NBE ?

• A particular type of invisible intense IC discharge of short (10 µs) duration which physics are up-to-date unknown.

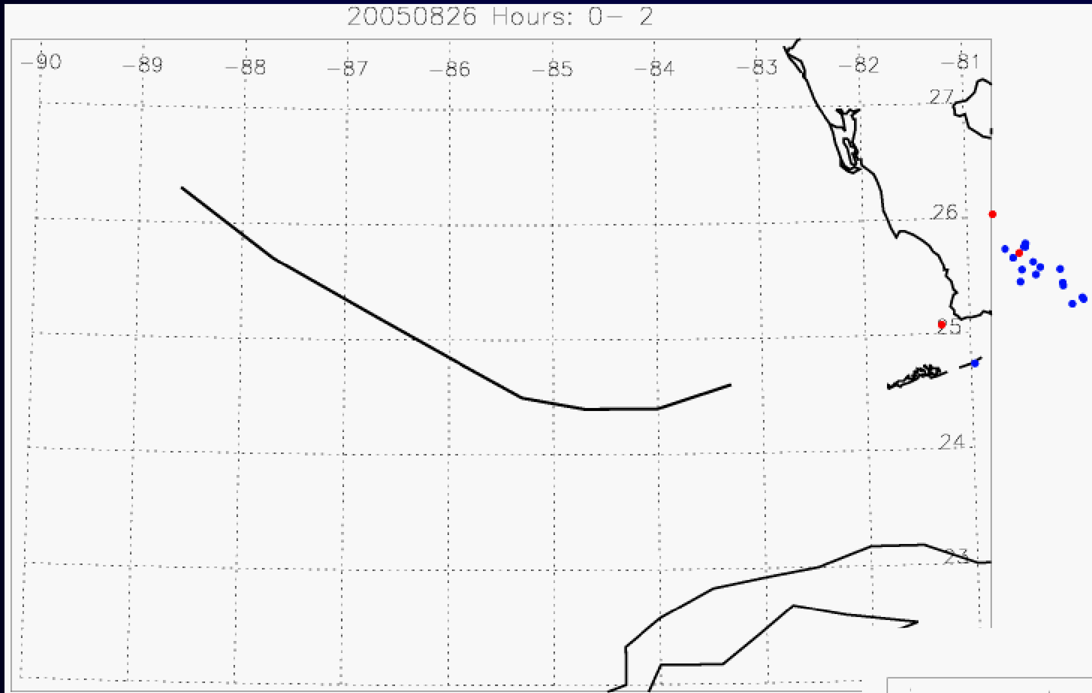
•Often observed within severe convection (such as tornadic supercells or MCS).

• Exhibit unique waveform signature →





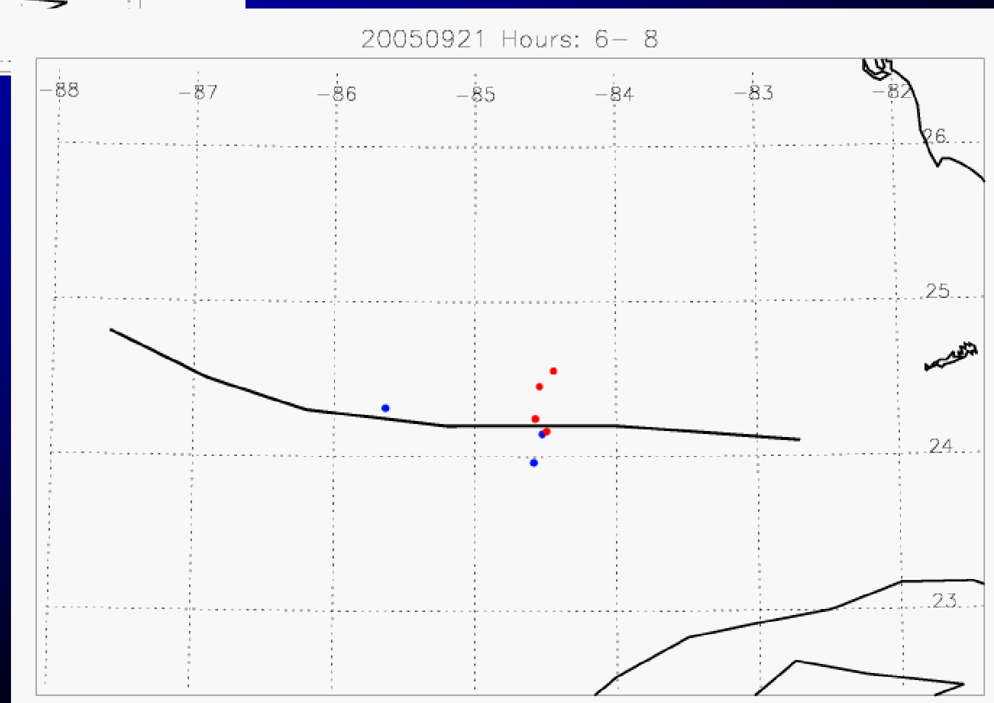
Mapping CG and IC: Katrina vs Rita



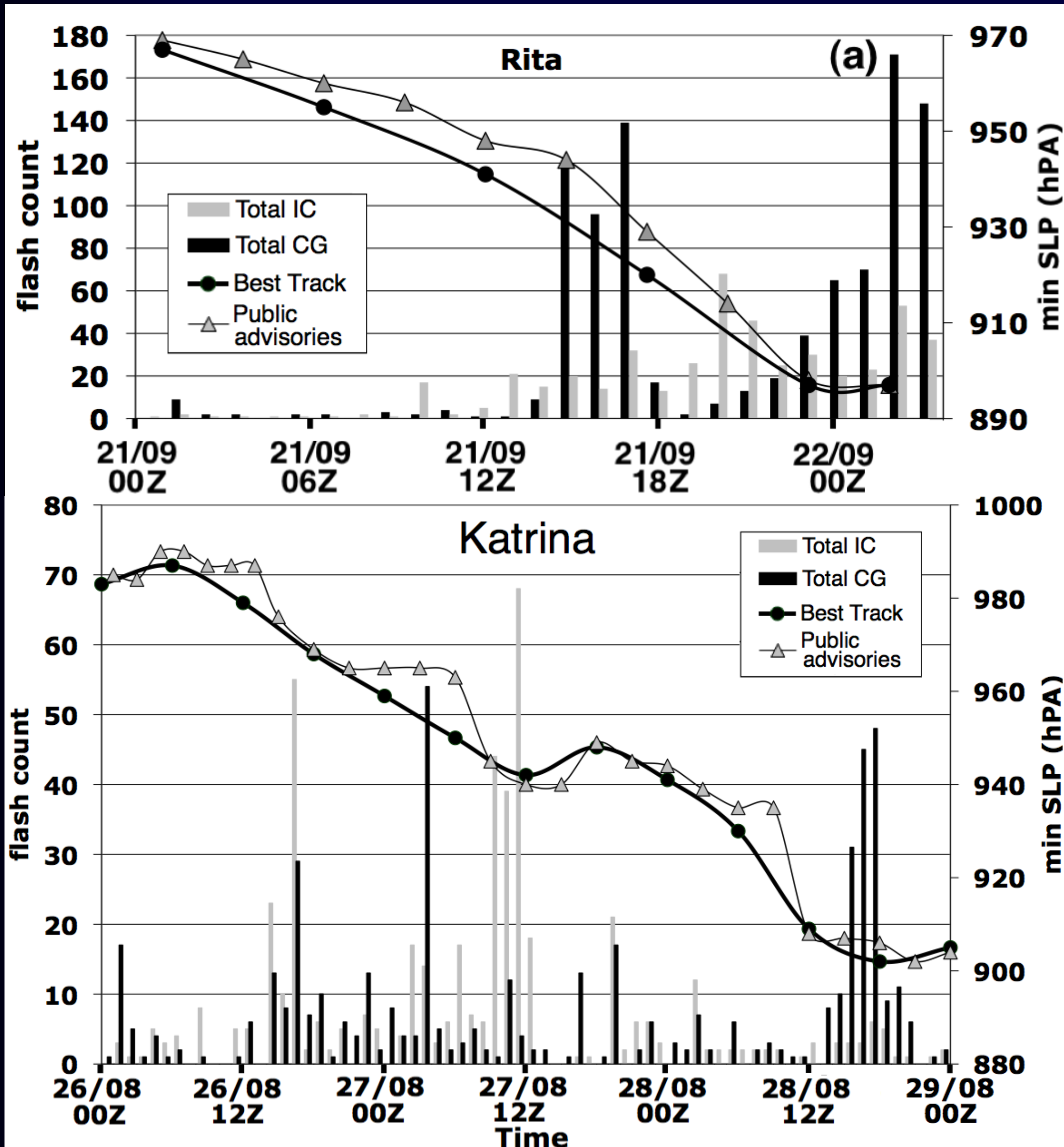
Katrina

Red = intra-cloud flash
Blue = cloud-to-ground flash

Rita

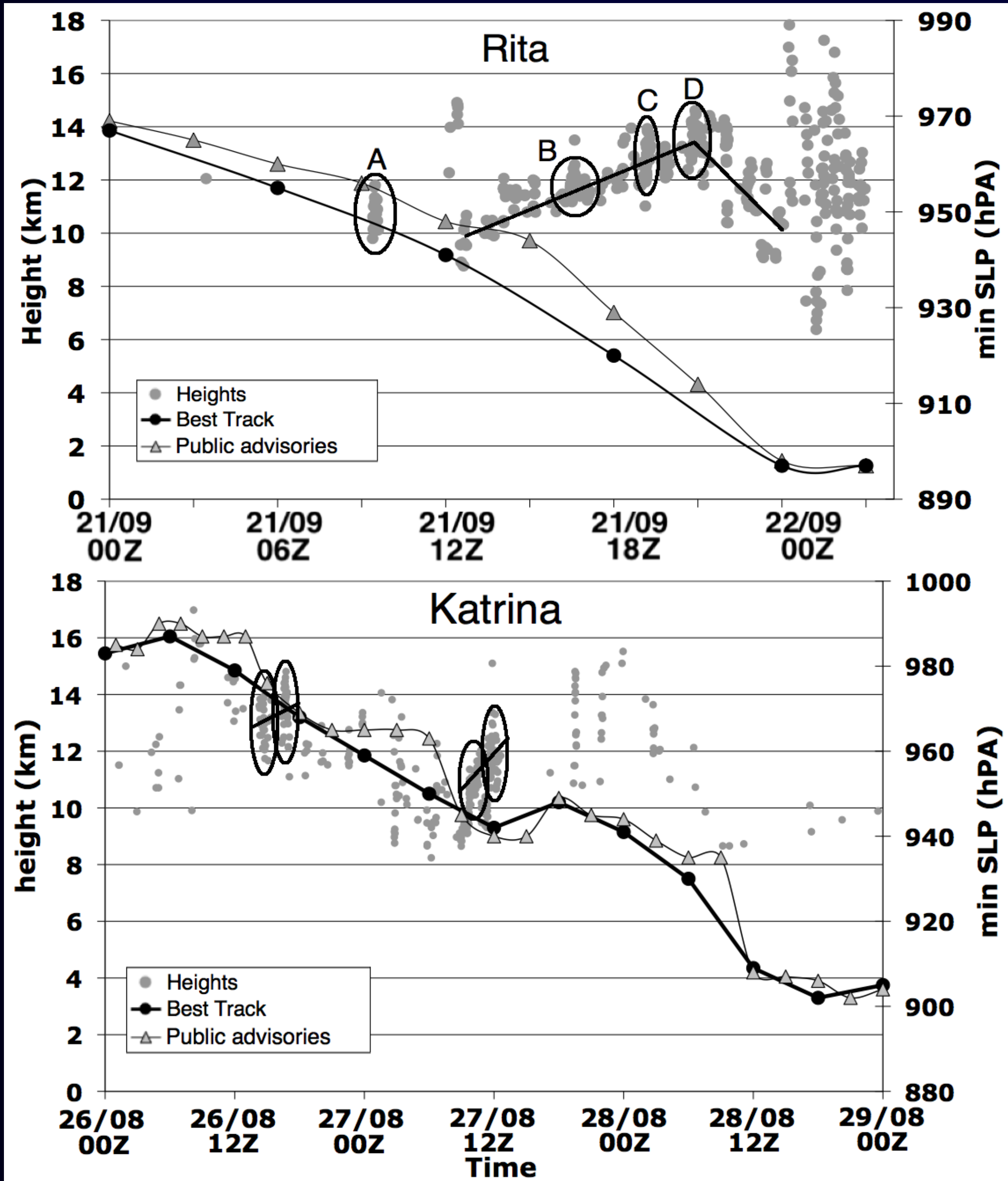


Lightning time series for Rita/Katrina

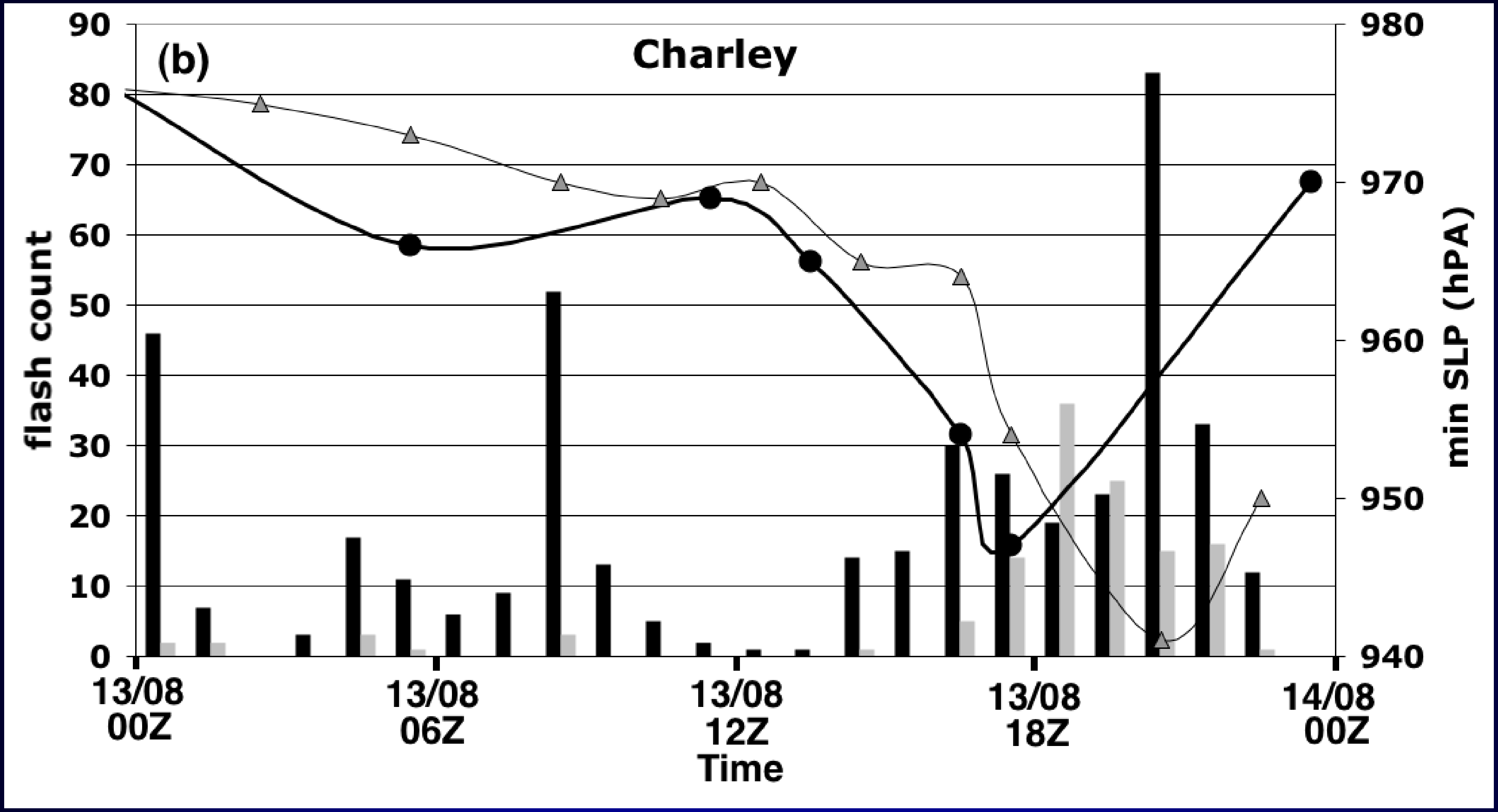


- Increase in both cloud-to-ground (CG) and intra-cloud (IC) flash rate during onset of RI
- Large CG flash burst observed during period of max intensity
- Same behavior seen for Charley (not shown)

NBE discharge heights evolution for Rita/Katrina

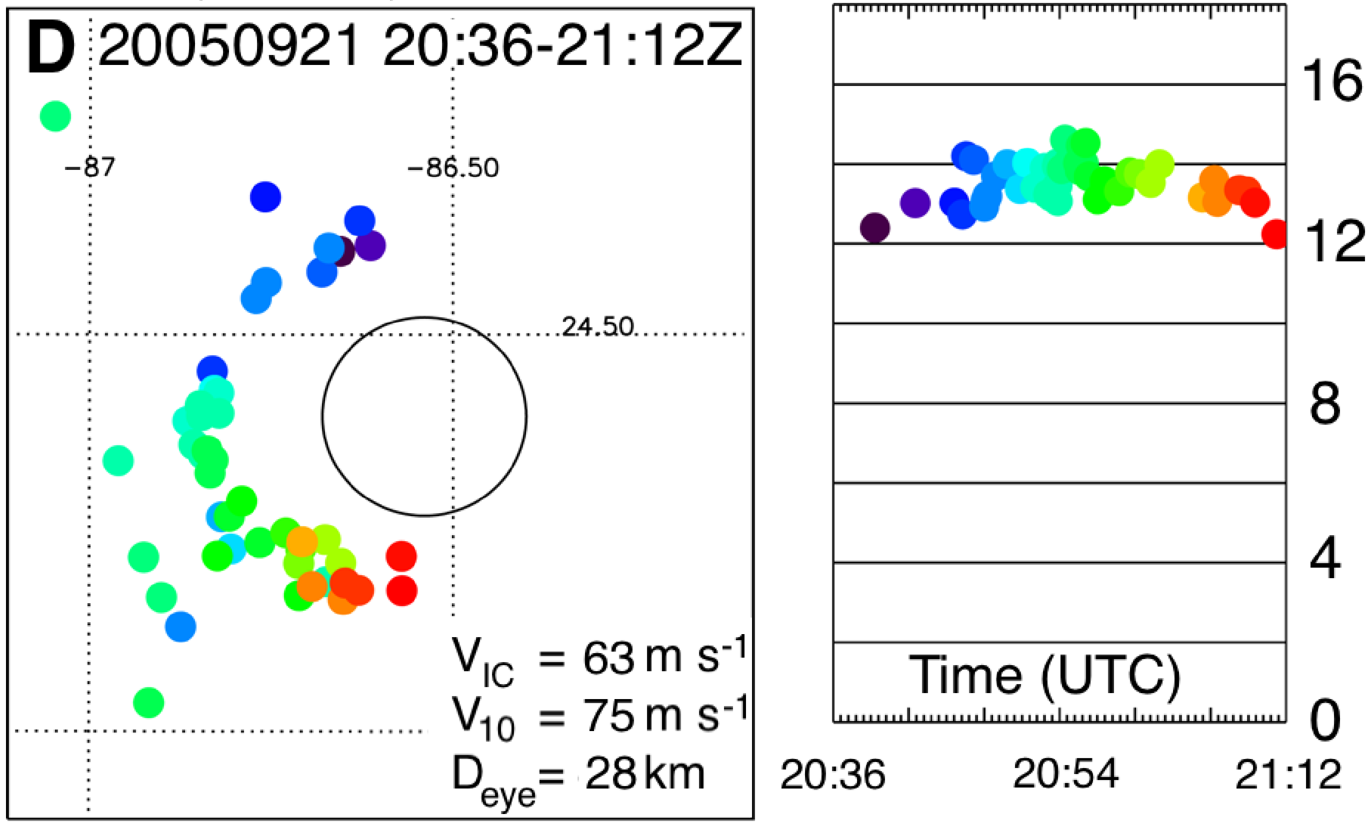


- Both storms experience NB increase in height during RI, especially Rita by ~ 4 km.
- Indicative of charge lofting during convective burst.
- For Rita heights decrease quickly ~3 h before period of max intensity → Indicative of collapse of hot towers.
- Same results seen for Charley (not shown).



•Similar results are found for Charley

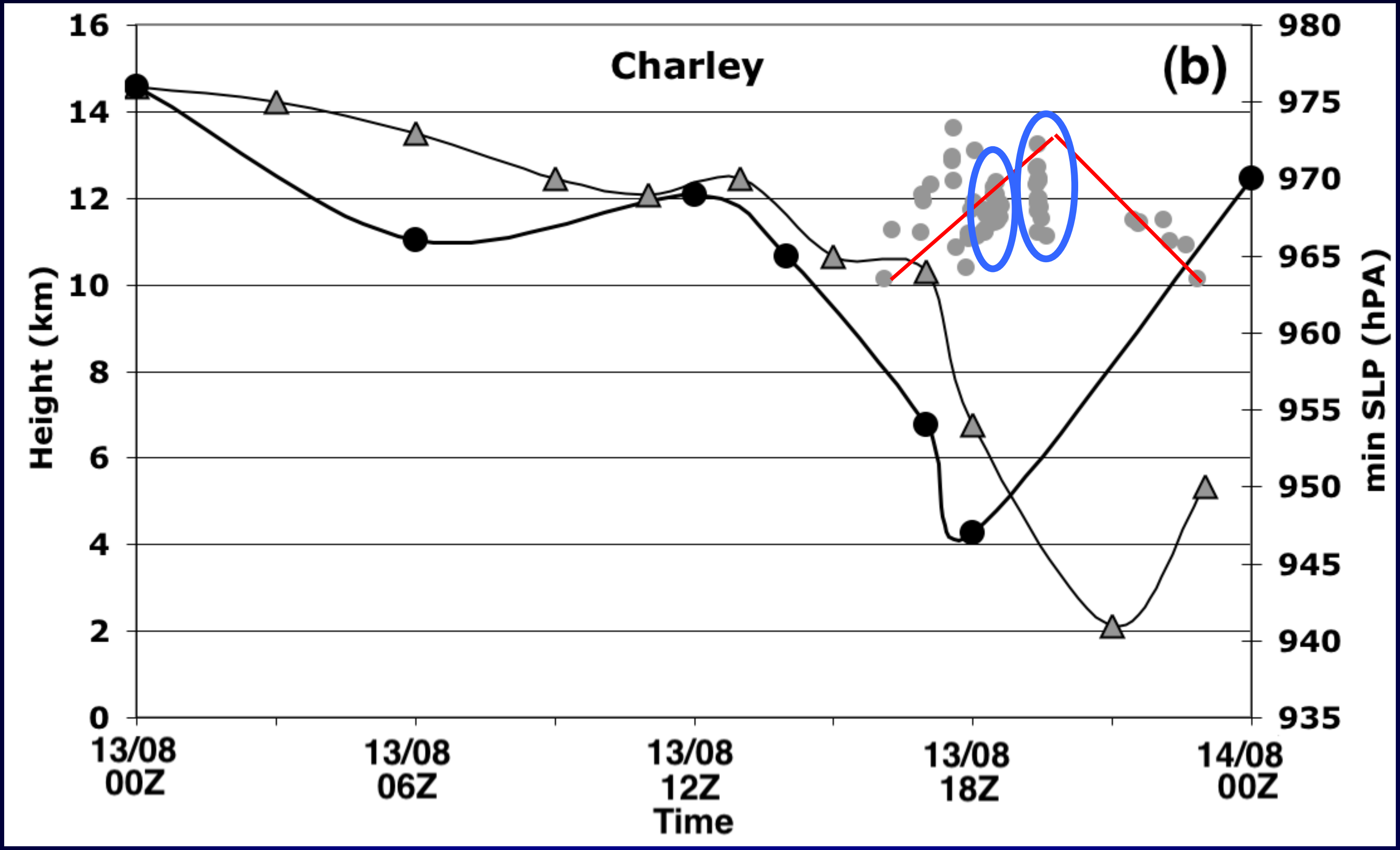
Rita: One more convective burst example…



V_{IC} = Intra-cloud lightning rotation speed

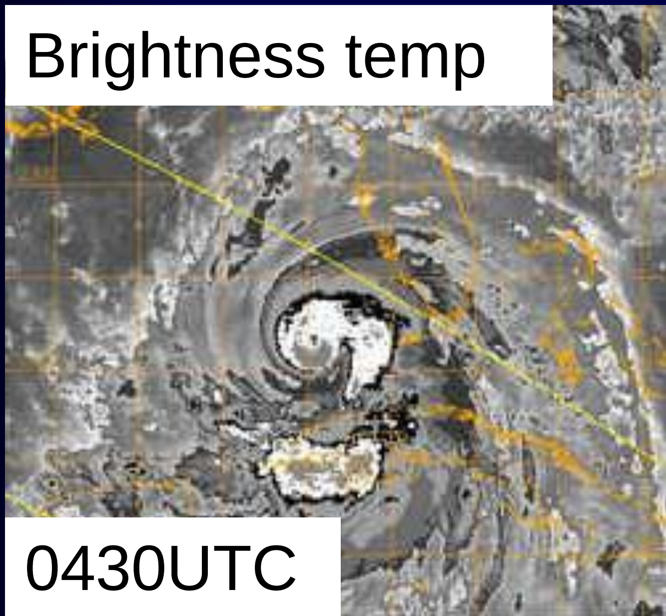
V_{10} = 10-m maximum sustained wind from NHC

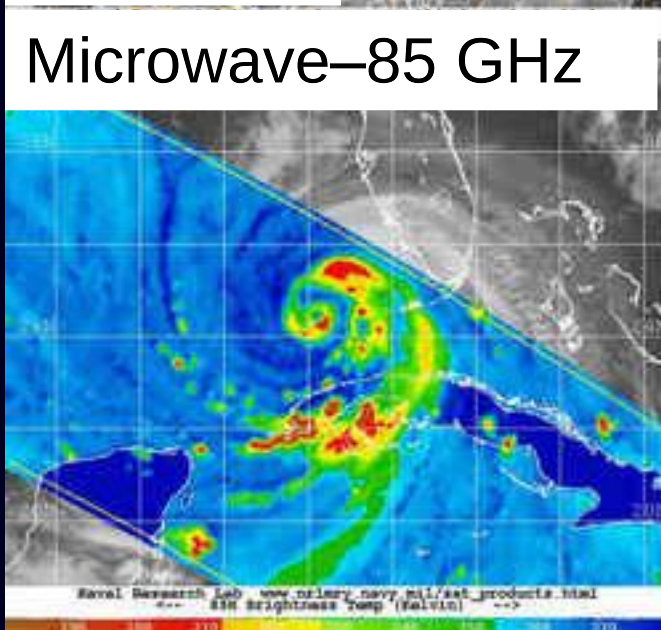
D_{eye} = Eye diameter

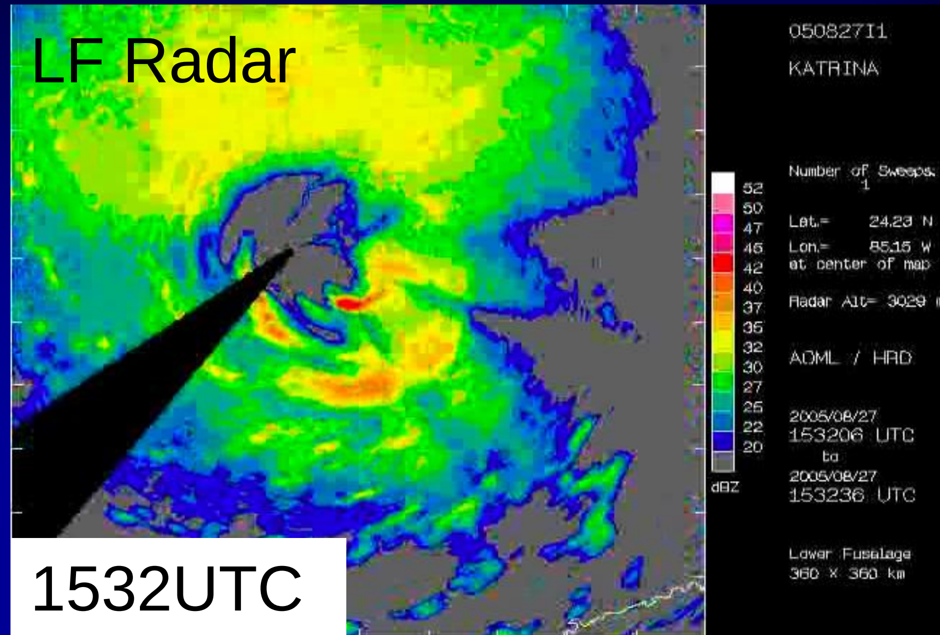


•Again, similar behavior seen for Charley

Katrina: NRL Satellite- NOAA Doppler radar imageries :







•Deep convection present on the southern portion of the eyewall 4h before and 5h after observations.

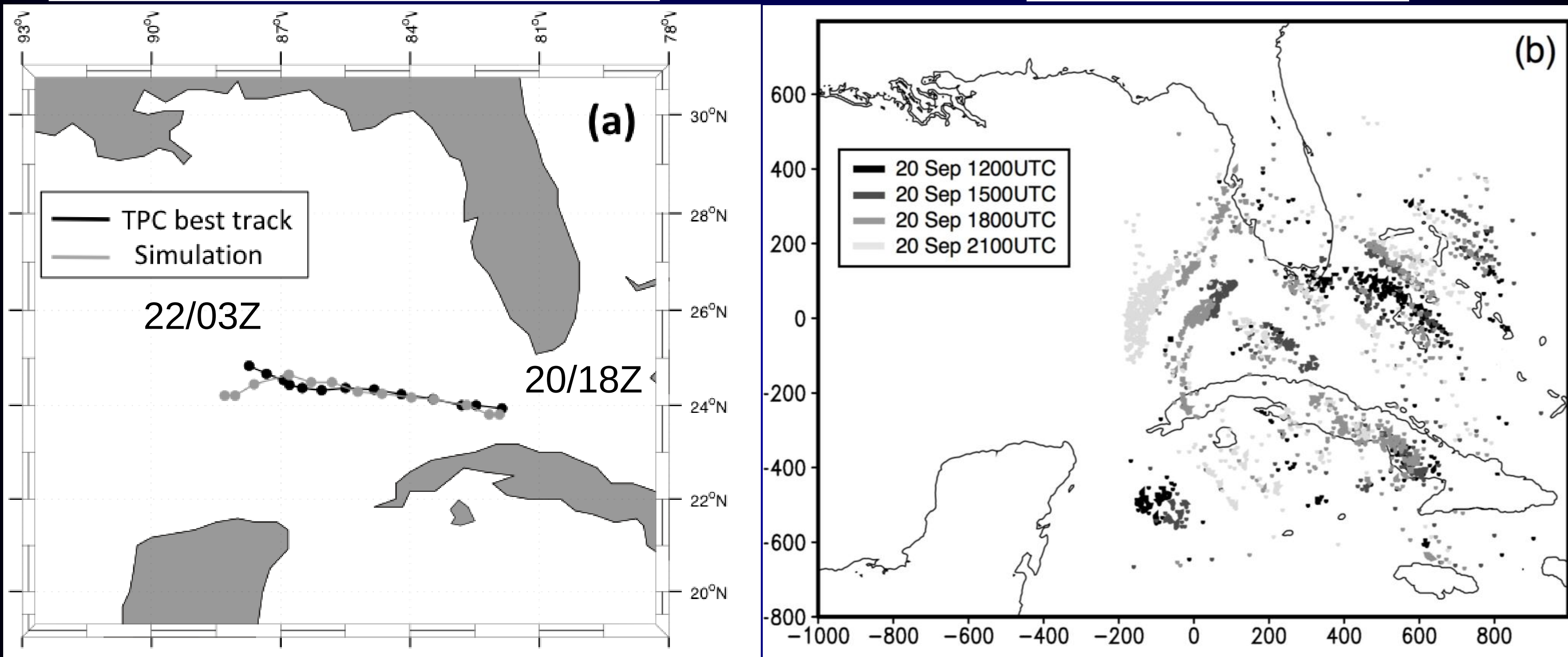
Obs: Conclusions

- Total lightning data was manually analyzed for 3 Atlantic major hurricanes and showed:
- An increase in CG *and* IC flash rate during the onset of RI
- A large increase in CG flash rate during period of max intensity
- An increase in NB discharge heights during onset of RI or intensification
- IC flash along with radar data allows one to track individual convective events (or hot tower bursts) in the eyewall.
- → Lightning (particularly IC flashes) can be used to fill in the voids of radar data for a better representation of storm core internal convective structure for use in data assimilation procedures (EnKF, 4DVAR etc..).

•4 km run used to provide reasonable Initial Conditions for 2 km run

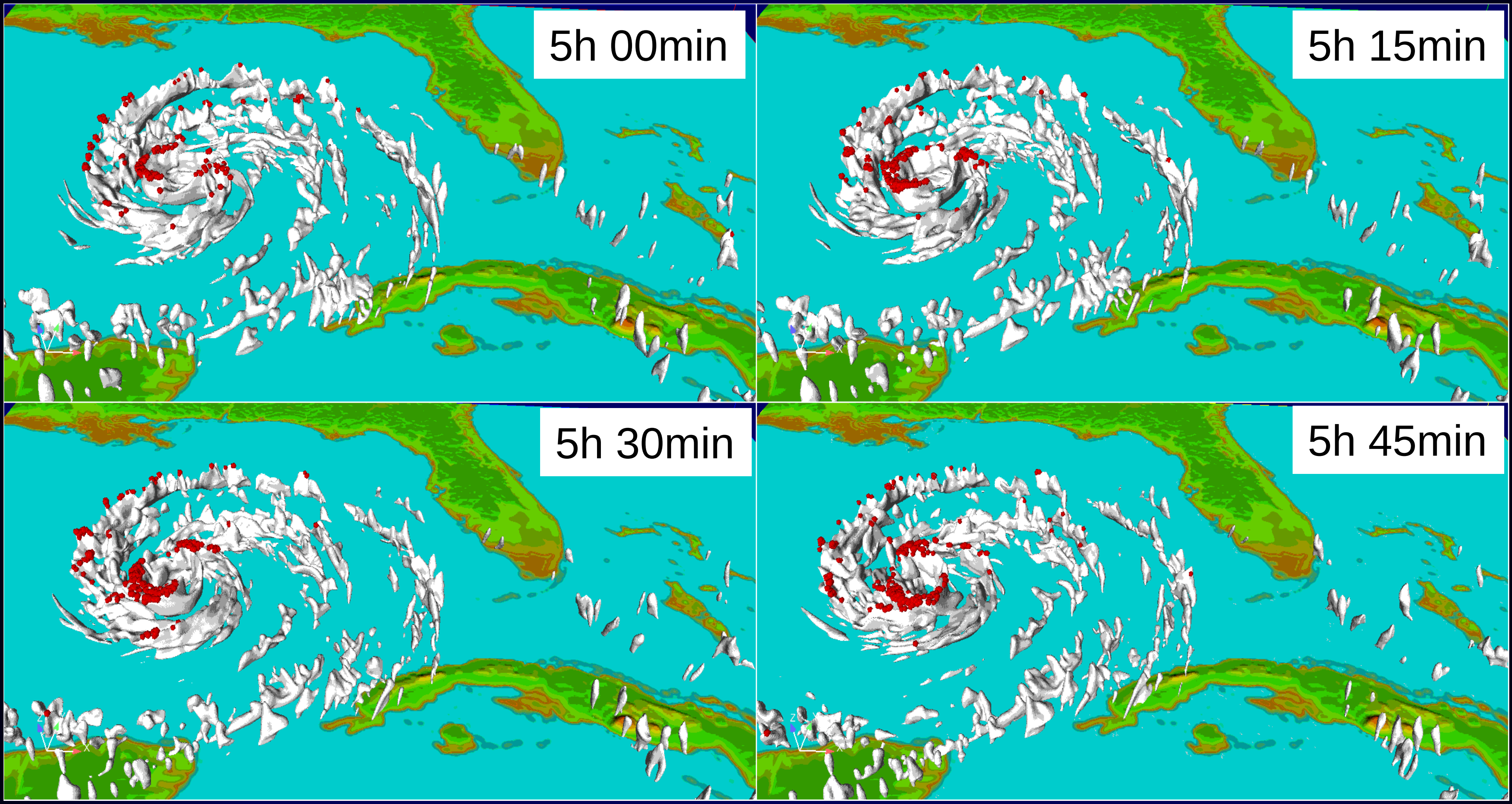
Modeled track for 4 km run

LASA lightning



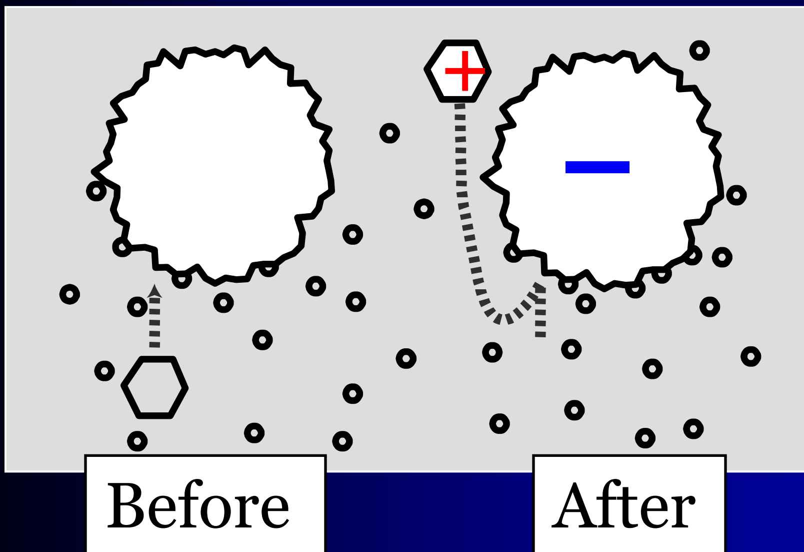
•Abundant rainband lightning in LASA data help to initialize bands and achieve a better balance between eyewal/rainband convection.
•Modeled Track matches obs reasonably well.
•Simulated storm intensity at time of restart of 2 km run (30h=21/19Z) is ~915 hPa vs 908 hPa for obs.

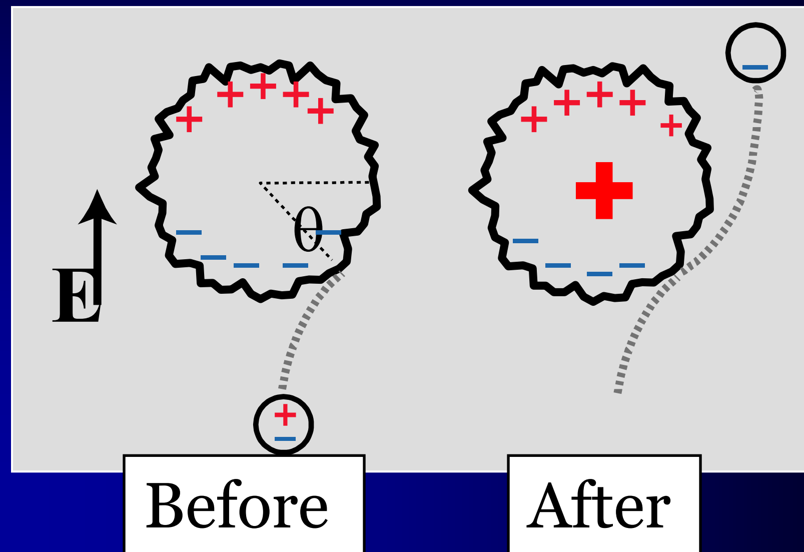
Closer view of the eyewall convection:
3D view of the burst:



- Red dot = flashes
- White isosurface = Cloud mixing ratio of 1 g/kg.

Parameterizing charge separation in a microphysical model





Non-inductive

$\vec{E}$ independent

Graupel-ice collision

Inductive

$\vec{E}$ dependent

Graupel-droplet collision

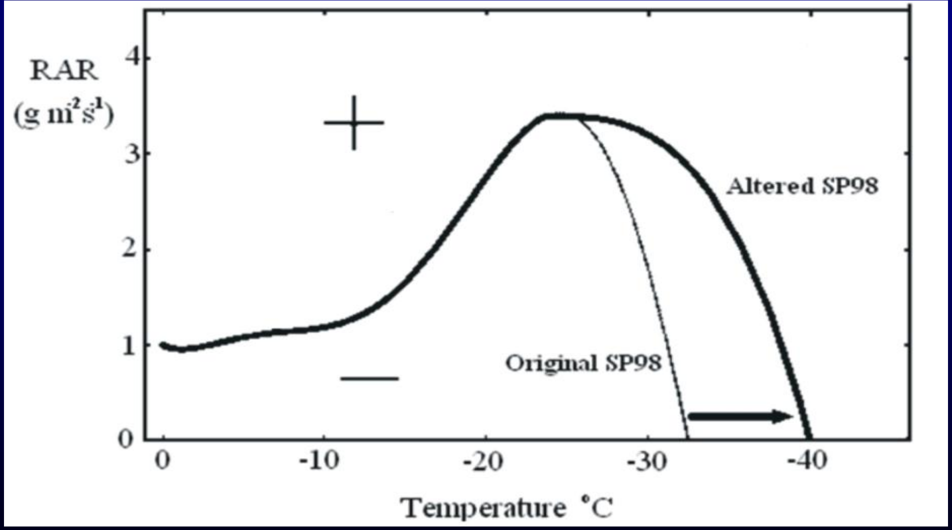
Non-inductive charging: Example

The charging rate and the sign acquired by the rimer (graupel) depends on:

Ambient temperature → AND → Effective LWC (Saunders 91)

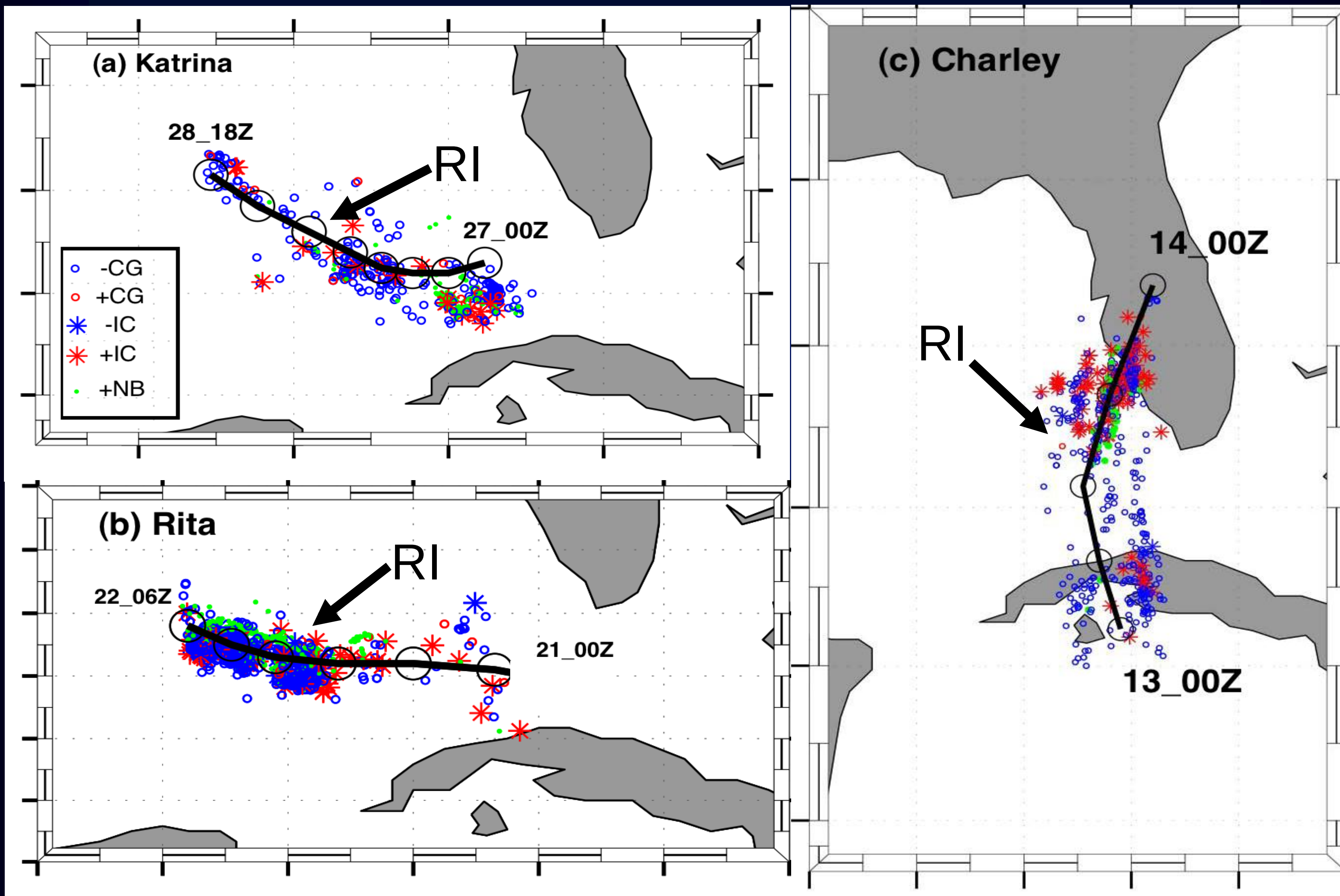
Ambient temperature → AND → LWC (Gardiner)

Ambient temperature → AND → Riming Accretion Rate (Saunders and Peck 98, RR Mansell scheme 2000)

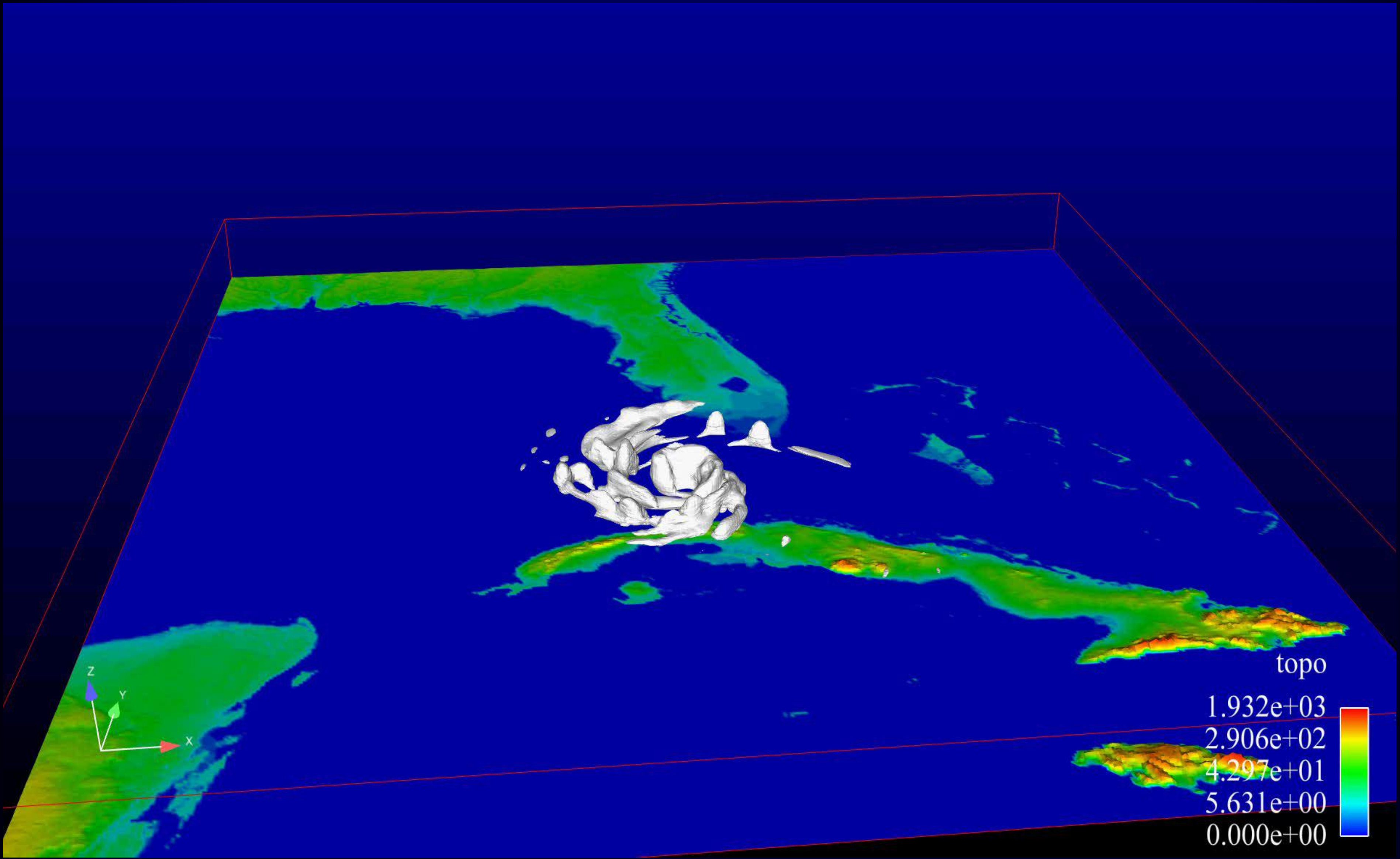


Saunders and Peck (1998)

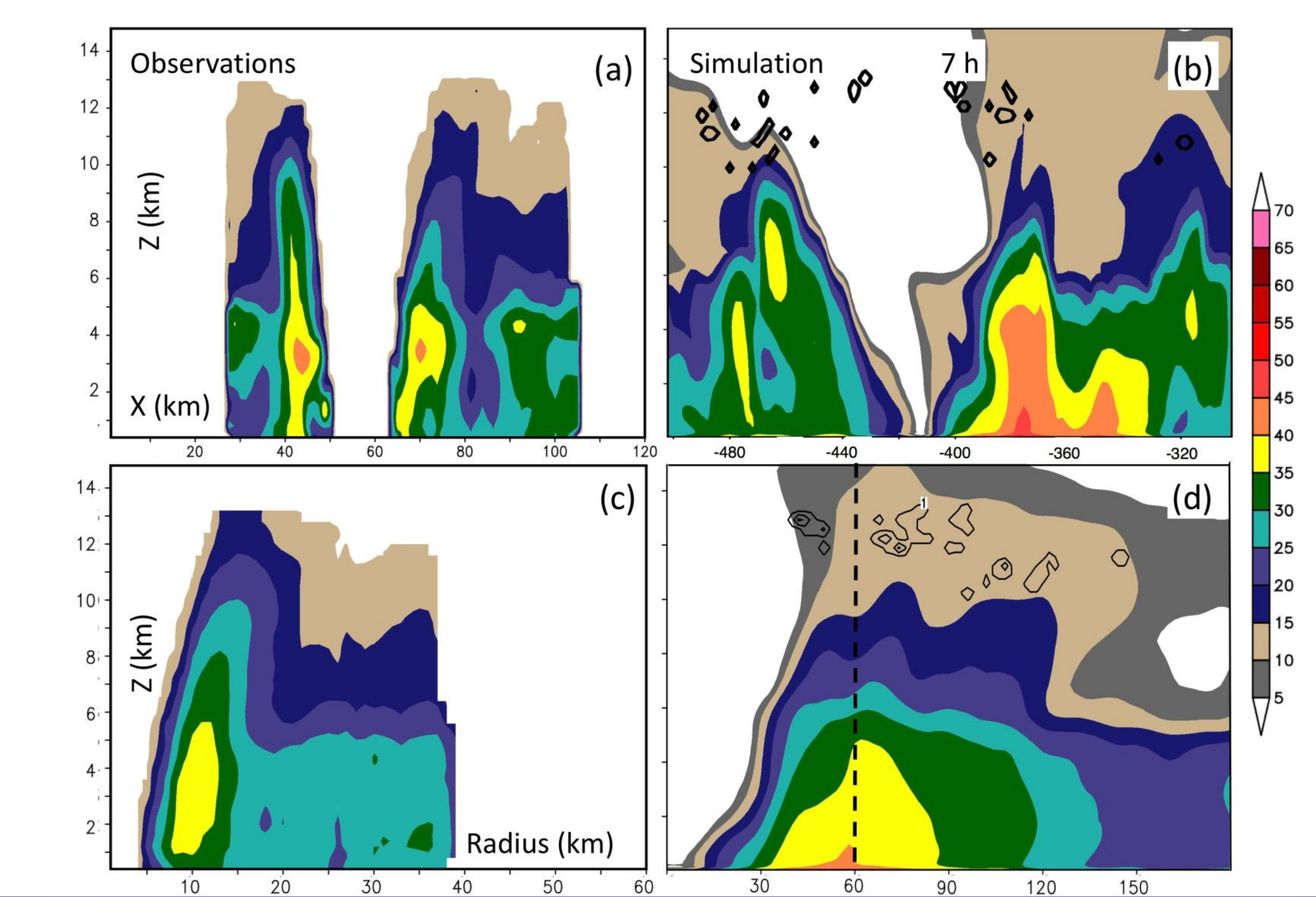
Mapping various lightning types



3D movie

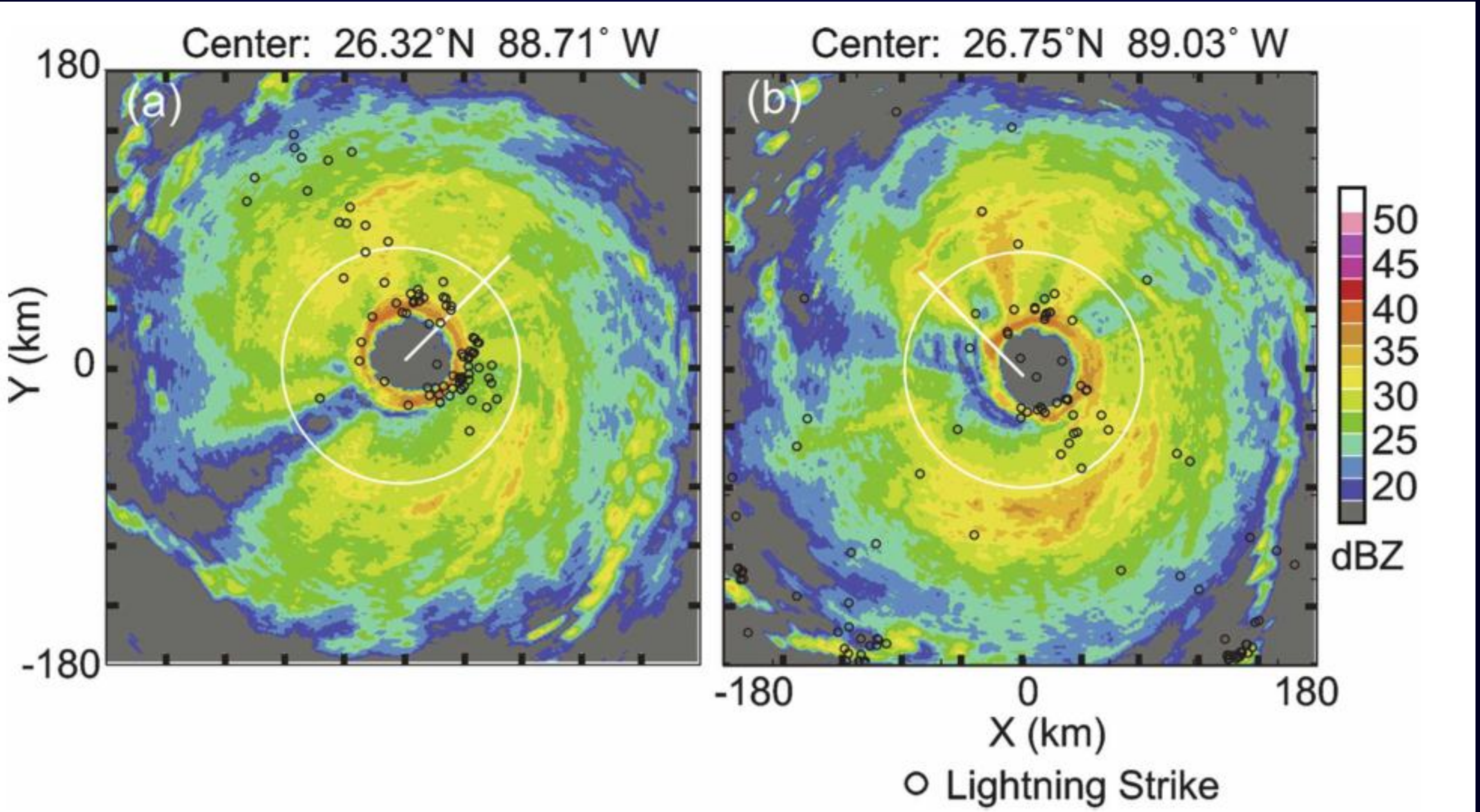


Simulated vertical/azimuthal structure vs obs



•Simulated eye size reasonable-
•Simulated 15,20,25 dBZ echo top in good agreement with obs.
•Eyewall width and hence slope, overestimated (eye/eyewall evaporation and/or surface friction)

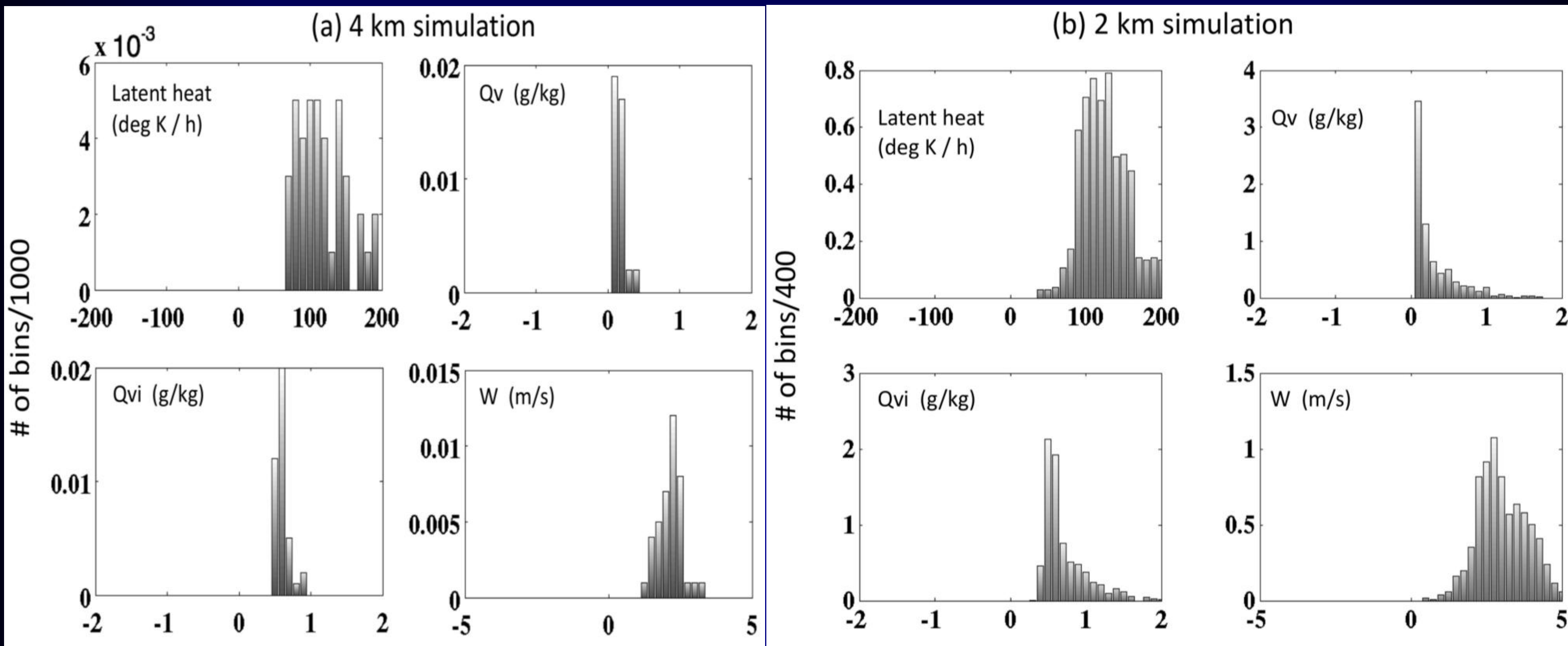
CG flash Observations (Squires and Businger 2008):



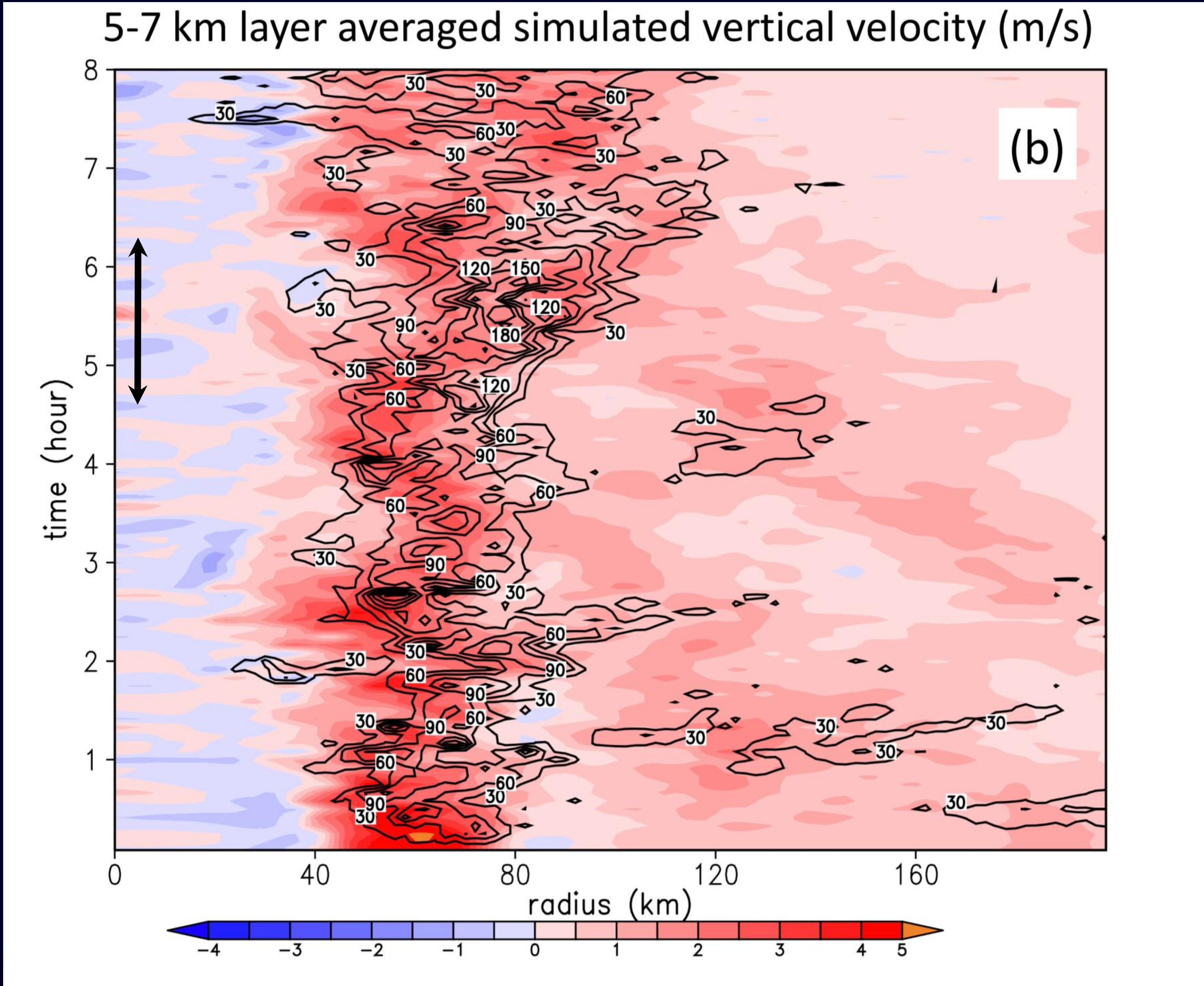
NOAA Aircraft Tail Doppler Radar

•little lightning in the rainbands compared to the eyewall at about the same time during RI.

Proxies/surrogates for lightning for use in operational models



•Lightning flash in model for both 2 and 4 km simulation associated with 2-4 m/s updraft speed, ~100 K/h latent heating (mainly from condensation/freezing) and water and ice super-saturation on the order of 0.5 g/kg.


5-7 km layer averaged simulated vertical velocity (m/s)
(b)
time (hour)
radius (km)
0
40
80
120
160
1
2
3
4
5
6
7
8
−4
−3
−2
−1
0
1
2
3
4
5